HYBRID AIRSHIPS:
INTRATHEATER OPERATIONS COST-BENEFIT ANALYSIS

GRADUATE RESEARCH PAPER

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Abstract

This paper examines the potential use of hybrid airships (HA) in an intratheater humanitarian assistance scenario. A linear programming model was used to study various mixes of hybrid airships, conventional airlifters, and sealift vessels. The main goal was minimizing the time needed to move 200 tons of cargo each day. The secondary aim was determining whether HA might be employed at less expense than conventional airlift or sealift assets.

The analysis determined that HA can be used to effectively and efficiently augment USTRANSCOM's current airlift and sealift capability. For medium-range distances (approximately 2,500 nautical miles one way), as many as five HA (each capable of lifting 40 to 50 tons) can help reduce or minimize total cargo movement time.

Based on 2011 operating costs, if expenses for hybrid airships are held below $3,000 per hour, they can be cheaper to employ than C-17s. If small cargo totals (i.e. 200 tons) must be moved as quickly as possible (or during sealift transit), then HA operating costs of $3,000 per hour or less also make them a less costly option compared to sealift. In comparison to C-5 and C-130 aircraft, HA "break even" hourly operating costs might be as high as $5,000.

To my wife and son

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Phil Lynch

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I. Introduction

Background, Motivation, and Problem Statement

Basic airship technology dates back to the start of the 20th Century (Botting, 1981:6). However, recent advancements in technology and development have caused resurgence in the potential utility of these craft. Modern hybrid airship prototypes combine lighter than air and heavier than air technology in different sizes and cargo weight carrying capabilities. United States Transportation Command (USTRANSCOM) is examining the use of hybrid airships (HA) for both intertheater and intratheater airlift missions.

Specifically, US TRANSCOM's Strategy, Policy, Programs, and Logistics Branch (J54) has been tasked to "lead command, DoD, and industry efforts to develop the long term CONEMP and economic feasibility of hybrid airships" (TRANSCOM, 2010:2). The four objectives for TRANSCOM are the following: "identify the use/need/capability gaps for hybrid airship employment," determine required HA capabilities, identify partner organizations, and develop a timeline for implementation (TRANSCOM, 2010:3).

Research Focus and Objectives

This research paper addresses the first of the four objectives listed above by examining potential HA augmentation of current DoD air and sea lift platforms during *intratheater* missions. It will build upon the work that has been accomplished so far in *intertheater* airship concepts of operation (Rapp, 2006). This paper has three main objectives. The first goal is to discuss the development, capabilities, and limitations of hybrid airships. The second is to identify where HA might be used to minimize or reduce the time required to move humanitarian

assistance / disaster relief (HA/DR) cargo to the area of need. The final objective is to associate operating costs with various combinations of HA, conventional airlift, and sealift used to transport relief supplies across intratheater distances.

The development of HA will be traced back to the origins and history of airships, then move to a discussion of current HA technology and prototypes. Planned payload, range, speed and altitude capabilities will be considered. Limitations such as vulnerability to hostile fire and amount of clear area required for takeoff and landing will also be discussed.

Quantitative analysis will then be used to determine the most effective use of hybrid airships in the intratheater airlift role. This will be accomplished using a mix of conventional aircraft, sealift vessels, and hybrid airships. The main research statement is that hybrid airships can be used in combination with airlift and sealift assets to provide comprehensive, effective intratheater lift capability.

Once an optimal level of effectiveness is modeled, this paper will attempt to readdress that model, with efficiency (operating costs) in mind. In some cases, effectiveness and efficiency may both be simultaneously optimized. In other instances—where it makes sense to do so—HA use can be manipulated to gain some efficiency while maintaining acceptable effectiveness levels for TRANSCOM's customers. This will manifest itself in terms of time, payload, and financial cost.

Methodology

This paper uses an "excursion from a base scenario" methodology. It demonstrates how hybrid airships could have been used to move humanitarian assistance / disaster relief (HA/DR) cargo from the US to Haiti in early 2010, as part of Operation Unified Response. A daily requirement of 200 tons of cargo was used, based on what was actually shipped to the

earthquake-stricken area. The main goal was to minimize the amount of time required to move this cargo from the continental United States, using the ports of Charleston, South Carolina and Jacksonville, Florida. A linear programming (LP) model was used to optimize the mixture of TRANSCOM assets on these routes, given realistic numbers of conventional aircraft, ships, and HA available (Ragsdale, 2008:178).

The objective during the initial stages of modeling was to meet a minimum payload threshold while minimizing enroute time. Several iterations were necessary to fully flesh out the best combination. Once this was complete, operating costs were used to show any financial benefit gained by using HA.

Data use to construct and feed this model was primarily obtained from USTRANSCOM, Air Mobility Command (AMC) Current Operations (A3O), and air operations centers involved in current (or recently past) humanitarian and combat airlift operations. Military Sealift Command (MSC) provided much of the US Naval ship data. Additionally, the 597th Transportation Brigade at Fort Eustis, Virginia provided insight into joint port opening operations and Army watercraft.

Assumptions and Limitations

As mentioned earlier, the scope of this paper is limited to intratheater operations. A distance of 2,500 nautical miles (NM) or less was used to represent this requirement, as explained later in this section (under "Operation Unified Response HA/DR Requirements"). Another key delimitation is that payloads were assumed to only flow ***to*** ports in Haiti. (No provision for "backhaul" cargo or passengers departing these bases was included in the model.) Also, refueling of aircraft and ships at the ports of debarkation (POD) was assumed to be

unfeasible. (They must be capable of completing a round trip from the CONUS to Haiti, then back to the CONUS without refueling).

Hybrid airships that are in prototype or development stages were not exempt from consideration in this paper. However, technology that is unproven or physically impossible was excluded. Proprietary technology details were not included in this paper. A maximum HA altitude capable of 12,000 feet above mean sea level (MSL) was assumed, since that is the likely highest altitude for any prototype designed as of 2010. HA block speed was held constant at 80 knots (nautical miles per hour).

Hostile fire against HA is addressed only in a general sense. (This paper does not analyze specific threat categories or systems (i.e. surface to air missiles (SAMs), anti-aircraft artillery (AAA), small arms, or air-to-air threats). The discussion remains at the unclassified level, but briefly addresses this.

Conventional Airlift

Only C-5, C-17, and C-130 aircraft were used when considering conventional airlifters. Although C-130J aircraft exhibit better performance than C-130E/H models, all C-130 aircraft were considered identical in terms of maximum range and payload capability required for this scenario model (Jackson, 2010:847). Aircraft such as the C-27J, CH-47, and CH-53 were excluded from this analysis because they are not capable of making the round trip between the CONUS and Haiti without refueling. (More specific assumptions are described in the following paragraphs, and are detailed in the “Literature Review,” “Methodology,” and “Analysis” sections of this paper.)

KC-10 and KC-135 airframes were not included in this analysis. They were assumed to be committed to air refueling missions rather than cargo transport. Commercial air cargo carriers

were also not included in this model. This was done to preserve the quick reaction capability of organic TRANSCOM (AMC) airlift assets, and narrow the scope of airlift analysis.

Aircraft utilization rates (or "ute" rates) were not considered in this model, because their applicability in this project is limited. This paper merely addresses the number of hybrid aircraft and/or conventional aircraft needed to most quickly move HA/DR cargo to the area of need. Since a fleet of hybrid airships does not yet exist, the crew and maintenance requirements have not yet been determined. Therefore, no particular hybrid airship from this notional fleet was used on more than one sortie in one 24 hour period. This assumption ensured the various number of HA missions flown in a one-day period could always be supported.

Sealift

The sealift assets used in the comparison include 4,000 (4K) twenty-foot equivalent unit (TEU) container ships, 1,000 TEU container ships, large medium-speed (LMSR) roll-on/roll-off (RORO) ships, fast sealift ships (FSS), ready reserve force (RRF) RORO, and the joint high-speed vessel (JHSV). Two types of US Army watercraft were also included in the analysis—the logistics support vessel (LSV) and landing craft utility (LCU) 2000 class "heavy boats" (Sullivan, 2011). (The new JHSV was used to a limited degree, since production on the first of up to 18 of these craft has started (USN, 2010).)

MSC no longer operates "break bulk" (BB) ships for international cargo movement (Gilbertson, 2011). Since the focus of this paper is on *USTRANSCOM's share* of HA/DR cargo requirements, break bulk ships were excluded from this analysis. (Gilbertson, 2011).

II. Literature Review

History of Airships

The first practical airships were flown successfully in the early 1900s (Althoff, 1990:1). Early airship design developed into three main categories—nonrigid, semirigid, and rigid. Nonrigid variants used multiple small bags (called ballonets) inside the main envelope to maintain the airship's shape and provide buoyancy. The ballonets were filled with either helium or hydrogen. Nonrigid airships encountered structural problems under heavy loads or adverse weather conditions. Designers combated this problem by adding a keel along the bottom of the envelope. These types formed the second class of airship; the semi-rigid. As engineering advanced, rigid airships were created. These were built around a larger keel, and supported by a metal endoskeleton framework (Botting, 1981:23).

By the 1930s, airships were capable of carrying payloads (cargo and passengers) weighing as much as 80 tons (160,000 pounds), at speeds up to 72 knots (Althoff, 1990:269). Notable vessels included the United States Ships (USS) Shenandoah, Akron, and Los Angeles, as well as the German Graf Zeppelin (Althoff, 1990:139). The most notorious of the early airships, however, was the German Hindenburg. The catastrophic explosion of this hydrogen-filled aircraft at Lakehurst, New Jersey on 06 May 1937 killed 36 people. Although 62 persons onboard the Hindenburg survived, the dramatic news coverage of the event hastened the end of the early airship era (Botting, 1981:167).

Small, nonrigid airships were used by military forces during World War II. Missions flown by both Allied and Axis forces included surveillance, reconnaissance, and naval escort (in an anti-submarine capacity). Large rigid airships did not play a major role in the conflict (Althoff, 1981:165). However, the US Navy actively pursued acquisition of nonrigid blimps

(Althoff, 1990:150). By March of 1944, the number of blimps operated by the US Navy had swelled to 119 (Althoff, 1981:199).

In the 1950s, lighter than air craft were still operated by the US military. However, as advances in conventional aircraft progressed, the use of airships declined. The last operational US Navy airship was built in 1960. The final flight of the program took place on 31 August 1962 (Althoff, 1990:261). Since that time, the only use of airships in the US has been for commercial operations, such as television camera coverage at sporting events.

Current and Future Airship Technology

Hybrid airships are so named because they combine “lighter than air” characteristics of legacy airships with modern heavier than air technology. Hybrid airships use a buoyant gas (usually helium) contained in a large fabric envelope to typically provide approximately 75 percent of the required lift. The remaining lift (about 25 percent) is obtained from the airfoil shape of the craft itself. Forward movement creates the relative wind needed to provide the additional lift (RAND, 2008:7). These percentages can change, with the static lift component ranging from 60 to 100 percent, and the aerodynamic lift component accounting for up to 40 percent (Holland, 2009:6). The main advantage of a hybrid airship over a conventional (or “legacy”) airship is that while stationary on the ground, it is heavier than air. Therefore, obtrusive towers and large numbers of personnel are not needed to moor the aircraft to the ground to prevent it from rising uncommanded into the sky.

A key concept in HA operation is “percent heaviness” (Rapp, 2006:60). In short, a hybrid airship should be operated so that it is always heavier than the surrounding air mass. This impacts controllability, landing, and ground operations. Therefore, it is critical to consider weight reductions due to fuel burn and offload of cargo and passengers.

The concept of static heaviness introduces two requirements associated with operating airships that are heavier than air—ground distance needed for takeoff and landing, and ballast requirements. Because a hybrid airship requires forward movement to provide a significant portion of its lift, it requires a lengthy area clear of obstacles to build up speed (during takeoff) or slow to a stop (during landing). This area does not necessarily have to be paved—or even extensively prepared. However, planners for operations using HA must identify critical landing zone (LZ) requirements as early as possible, since necessary distances could range from 4,500 feet to 10,000 feet (Rapp, 2006:31).

As mentioned earlier, the static heaviness of a hybrid airship must be maintained above zero. In many cases, this requires ballast to be onloaded to compensate for the weight of payload that is removed from the airship at its destination. This material could be sand or—more commonly—water (RAND, 2008:7). Additionally, if significantly more fuel is burned enroute than planned, the static heaviness may approach zero. This contingency requires ballast to be onloaded prior to landing, to maintain it above zero (Rapp, 2006:63).

Both non-rigid and rigid airship crews can also increase their static heaviness by venting helium from the craft (RAND, 2008, 36). However, this option is not preferred, because replenishing the lost helium can be costly and time consuming (RAND, 2008: 36).

Rigid airships can make use of another option to reduce (or potentially eliminate) ground run distance requirements. One potential HA manufacturer has developed a system called "control of static heaviness" (COSH) (Aeroscraft, 2011). The specific details of this technology are proprietary, but the general concept is that some of the helium onboard is compressed and stored in internal tanks (RAND, 2008:36). This concept facilitates near-vertical landing performance. It also allows the helium to be re-introduced later to provide a vertical (or near-

vertical) takeoff capability, add lift if payload is added at a follow-on location, or potentially be recycled for later missions.

In summary, larger clear areas on the ground are required to launch and recover hybrid airships at locations where little or no ballast material is available. The clear area needed for takeoff and landing can be reduced if a particular airship operating there employs technology that compresses the helium gas onboard, and stores it for later use.

Types of Hybrid Airships

As of early 2011, the only prototypes or scale models of hybrid airships that have flown or performed taxi tests have been non-rigid designs (Holland, 2009:8). However, several companies are pursuing rigid airship development. Advantages of non-rigid HA over rigid craft include better survivability, simpler construction, and less complex technology. While some rigid designs may not be feasible for up to 10 years, their advantage is self-contained buoyancy control. This eliminates the need to onload and manage ballast material (Holland, 2009:27). Intermediate semi-rigid HA designs are also being pursued, although the most promising designs for hybrid airships seem to be either rigid or non-rigid (RAND, 2008:35).

A 2006 graduate research project written by Major Timothy Rapp for the Air Force Institute of Technology explored the use of ultra large hybrid airships for intertheater transport. Part of his literature review examined the history of airships, as well as the development of hybrid airship technology up to the year 2006. In 2008, and RAND Corporation published a study for “Project Air Force” titled “Military Potential of Hybrid Airships.” That study comprehensively analyzed the hybrid airship technologies that had been proven to that point, and noted technological challenges that lay ahead.

This research paper will not exhaustively repeat those two studies. However, it is important to establish a baseline of progress in the hybrid airship industry. Some of the sources these two projects cite have also been used to obtain information for this report. Scholarly and scientific journals, contractor-provided specifications, and independent US Department of Defense analyses were used to form a comprehensive picture of the current capabilities and limitations of hybrid airship designs, as of March 2010.

Table 1 lists various types of hybrid airship prototypes that have been recently designed. Data fields include contractor name, HA designation, body type, whether a prototype has actually flown, proposed payload, speed, altitude and range capabilities, and whether ballast or helium compression ("COSH") will be employed. Appendix A contains illustrations of six HA concepts/prototypes.

Table 1. Hybrid Airship Designs

Contractor	HA Designation	Body Type	Prototype Flown?	Payload (Short Tons)	Speed (Knots)	Max Alt (Feet MSL)	Max Range (NM)	Ballast or COSH
Aereon	Aereon 26	(Aero body test bed)	Yes (1971)	N/A	N/A	N/A	N/A	N/A
Aereon	Dynairship	(Lifting body concept)	No	N/A	N/A	N/A	N/A	N/A
Aeros	Aeroscraft ML 866	Rigid	No (as of April 2011)	60	100(cruise) 120 (max)	12,000	3,100	COSH
Boeing-Skyhook	Skyhook Heavy Lift Vehicle (HLV)	("neutrally buoyant")	No (planned for 2014)	40 (sling load)	60		200	
HAV *	Sky Kitten	Non-Rigid (1/6 scale prototype for Sky Cat 20)	Yes (2000)	N/A	N/A	N/A	N/A	N/A
HAV	Sky Cat 20	Non-Rigid	No	20	78 (cruise) 92 (max)	9,000 or 18,000**	1,225 (4,000 empty)	Ballast
HAV	Sky Cat 50	Non-Rigid	No	50	104 (cruise)	9,000 or 18,000**	1,250 (4,000 empty)	Ballast
HAV	Sky Cat 200	Non-Rigid	No	200	90 (cruise) 110 (max)	9,000	3,225	Ballast
HAV	Condor 104 (HAV-3)	Non-Rigid	Yes (2009)	< 1				
HAV	Condor 304	Semi-Rigid	No (planned for mid 2011)	< 2	80 (max)			Ballast
Lockheed Martin	P-791	Non-Rigid	Yes (2006)	undisclosed (3-5 tons ?)	undisclosed	20,000	undisclosed	Ballast
Ohio Airships	Dynalifter	Semi-Rigid	1/6 scale model taxi test (2006)	160				

***** Hybrid Air Vehicles (HAV): Formerly Aerospace Developments/Airship Developments, then became Airship Industries, then Advanced Technologies Group (ATG), then SkyCat. Development of SkyCat continues under HAV/HAC (Hybrid Aircraft Corporation).

**Indicates high-altitude version

(Sources: (Author-produced table using information from contractor websites, Carter, Dornheim, Sklar, Tuttle; various years)

As shown in Table 1, Aeros, Boeing, and Sky Cat/HAV are all relatively close to producing hybrid airship prototypes that can lift payloads of 20 to 60 tons (and, in one case, perhaps as much as 200 tons). Lockheed Martin is also a viable candidate for producing a practical HA (Slife, 2009: 20). It is also significant to note that Aeros is actively working to develop its COSH technology. In fact, this capability was successfully demonstrated in July 2008 (Aeroscraft, 2011).

Although several existing papers and presentations tout the benefits of HA capable of lifting 500 or even 1,000 ton payloads, these variants will not likely be feasible for at least 10 years (RAND, 2008:3). In 2005, the US Defense Advanced Research Projects Agency (DARPA) Walrus program studied the feasibility of constructing an airship capable of moving 500 tons a distance of at least 12,000 NM. At the time, DARPA concluded this was "not technically feasible," due to a requirement to use no ballast material other than ambient air (Moss, 2006:51).

In general, the near-term demonstrated capabilities and limitations indicate that HA can be fielded within 5 to 8 years to move payloads of approximately 60 tons (Tuttle, 2008:18). Commercial industry is currently interested in airships that can move these smaller payloads. For example, The Boeing-Skyhook heavy lift vehicle (HLV) prototype is being designed for carrying sling-loaded cargo to and from remote areas. It is a lighter than air variant augmented by rotary wings to provide lifting power for payloads (dynamic lift) and propulsion (Carter, 2008:60). This type of design is also referred to as "neutrally buoyant," since the lift provided by helium exactly overcomes the weight of the craft itself. Variable-direction propulsion systems provide the lift necessary to raise 40 tons (Boeing, 2008:1). This will ostensibly make it

safer and capable of lifting greater payloads than conventional helicopters. The first Skyhook HLV is scheduled to fly in 2014 (Sklar, 2009:23).

The DoD has also been pursuing development and acquisition of a joint future theater lift (JFTL) vehicle that can deliver payloads of 20 to 36 tons to unimproved landing zones. It is being examined for intratheater, strategic, sustainment, and joint forcible entry lift purposes. The specific intratheater lift requirements are distances of 250 to 1,000 NM in radius (500 to 2,000 NM round trip), with a vertical takeoff and landing (VTOL) or short takeoff and landing (STOL) distance of less than 1500 feet (Keck, 2009:16).

Notional Hybrid Airship Planning Payloads

This paper examines three notional HA payload weight values—50 tons, 30 tons, and variable between 31 and 49 tons. These represent HA capabilities that might be realized within only a few years, but still can provide useful amounts of intratheater lift. While 50-ton payload variants of HA have been prototyped already, 100-ton and larger vessels have yet to be built or flown. Therefore, a practical near-term TRANSCOM application for hybrid airships is the use of 50 ton (or smaller) vessels in HA/DR operations within the next 10 years (RAND, 2008:3).

The first quantity considered for implementation is 50-tons. This figure was calculated by averaging the projected payload capabilities of the Aeroscraft ML 866 (60 tons) and the Boeing-Skyhook HLV (40 tons). In this case, 50 tons is both the mean and median value.

A 30-ton HA was also considered. This value was selected because it is the mean payload of the SkyCat 20 (20 tons) and the Boeing-Skyhook HLV (40 tons). The notional 30-ton payload variant also provides a second choice of HA that could likely be fielded earlier than a 50-ton variant, and might be cheaper to operate.

Payloads ranging between 31 and 49 tons were also factored into the analysis. This allowed the cargo amounts carried by HA in the LP model to be adjusted (in one-ton increments). It also provided more detailed comparison between HA and conventional airlift platforms.

HA Survivability and Limitations

A popular misconception is that hybrid airships are extremely vulnerable to hostile fire. However, this is not true (Tuttle, 2008:17). According to a 2007 study by the RAND Corporation, thousands of rounds of small arms or anti-aircraft artillery are required to down an HA. Even strikes from man-portable air defense systems (MANPADS) might only disable an HA to the point where it would make a forced landing within four hours (RAND, 2008: 31).

There are many reasons for the increased survivability of these craft. The most influential is the low pressure difference between an airship's hull and the atmosphere. Another "built-in" defense against attack is the fact that many airships use multiple envelopes to contain the buoyant gas. The net result is an extremely slow leak of gas, even if multiple punctures are inflicted to the outer skin (RAND, 2008:31).

Although hybrid airships are potentially rugged enough to survive in threat environments, this paper will only address non-combat missions such as humanitarian assistance and disaster relief. Furthermore, due to two major limitations in demonstrated prototype technology so far, this paper will focus on operations near coastal areas. These two limitations are the maximum altitude capable with payload and the potential requirement to onload ballast (likely water) prior to landing.

The highest proposed altitude for HA carrying significant amounts of payload is in the 9,000 to 12,000 MSL range (Contractor websites; Rapp, 2006:7). While rigid airship design

shows promise in developing self-contained systems to reduce buoyancy (and therefore ground run distance) without needing to vent helium or onload ballast, this has yet to be comprehensively demonstrated (RAND, 2008:36). Therefore, coastal areas are amenable to lower altitude profiles, and also allow the opportunity to onload seawater for ballast.

The clear area requirements for landing and takeoff have already been mentioned. This paper will not discuss those in great detail. However, this is a crucial part of HA operations that must be addressed. Specific implications of this with respect to potential off-airport landing zones in Haiti are mentioned in section V ("Conclusions and Recommendations").

Operation Unified Response

The earthquake that necessitated Operation Unified Response occurred on 12 January 2010. Measuring 7.0 on the Richter Scale, it devastated Haiti's capital city of Port au Prince and the surrounding areas (Margesson, 2010:1). Over 220,000 people were killed, and approximately 300,000 were injured. More than one million lost their homes in the disaster (Handwerk, 2011:1).

The seaport at Port au Prince was severely damaged. Both piers had collapsed. The RORO ramps were out of commission. Furthermore, the support structure for the equipment used to offload ships had shifted, rendering it useless (Sullivan, 2010:3). The city's main airport (Toussaint Louverture International) control tower was damaged. However, the runway and most other surfaces remained useable for air operations (Margesson, 2010:1).

Humanitarian assistance and disaster relief operations (HA/DR) for Haiti began almost immediately. Aid from various nations, non-governmental organizations, and private parties began moving toward the island nation. The US military joint port opening team and

contingency response element (CRE) arrived in Haiti less than 42 hours after the earthquake (USTRANSCOM, 2010:5). By 15 January, the airport was receiving flights with aid cargo onboard. By 17 January, the airport that normally handled less than 20 flights per day was receiving well over 100 aircraft each day (Mendoza, 2010:2 and USTRANSCOM, 2010:7).

Operational seaports further from the major point of need (Port au Prince) included Cape Haitien (in Haiti) and Haina (in the Dominican Republic). These are located approximately 150 and 195 statute miles, respectively, from Port au Prince. Assuming roads in good repair, favorable weather conditions, and no border crossing issues between the Dominican Republic and Haiti, it might require three to five hours for a surface vehicle to transit this distance with some small amount of cargo transloaded from a ship.

Repair on the Port au Prince seaport began on 17 January. Fortunately, enough work was completed in time to receive the first LCUs there on 21 January (Sullivan, 2010:5). “Sealift in earnest” began four days later (25 January), when the main sealift flow began arriving at Port au Prince (USTRANSCOM, 2010:7).

Based on historical data provided by USTRANSCOM, the average daily amount of relief supplies inbound to the Port au Prince region between 12 January and 24 February was 1 million pounds (or 500 short tons). Of this total, the US military carried approximately 400,000 pounds (200 ST) each day. The remaining 600,000 pounds (300 ST) was transported by commercial carriers and/or non-US states (VanHoof, 2010).

Planning Factors for Intratheater Airlift and Sealift

Operation Unified Response HA/DR Requirements

A distance of 956 NM between the CONUS and Haiti was used in this study. The details of this calculation are outlined in the "Methodology" section. In essence, this represents the distance between the southeast US and Port au Prince. Due to lack of fuel availability (and a need to minimize ground time at Port-au Prince (Toussaint Louverture International Airport), this paper assumes that an aircraft, ship, or boat would have to transit the 956 NM distance twice without refueling, and still maintain reserve fuel requirements. Therefore, this study explores the use of small hybrid airships over "intratheater" distances defined as less than or equal to 2,500 nautical miles (NM). (This upper mileage limit is coincident with a distance category used in Air Force Pamphlet (AFPAM) 10-1403 (Air Mobility Planning).)

According to the United States Agency for International Development (USAID), the majority of relief supplies sent to a disaster area will consist of dry goods and other small pieces of cargo. Relief agencies typically do not transport large amounts of rolling stock into such regions. Additionally, drinking water is normally procured and purified on-site. Transport of bottled water into a region is unusual (Legates, 2011).

While the transport of large and outsized vehicles is typical for many DoD operations, this requirement is outside the scope of this paper. Therefore, HA/DR payloads will be assumed to be interchangeable between hybrid airships (HA) and conventional airlifters. HA are likewise assumed to be capable of carrying the contents of ship-borne 20-foot equivalent units (TEU), or perhaps even entire TEU containers.

Conventional Airlift Planning

To facilitate comparison with hybrid airships, the LP model in this study uses three main characteristics of conventional airlift and sealift platforms—payload capacity, block speed, and hourly operating cost. Table 2 summarizes the main parameters of the conventional airlift aircraft used in the LP model. AFPAM 10-1403 (Air Mobility Planning) was used to determine planning cargo capacity and block speeds for the three conventional airlift platforms examined (see Appendix B). It assumes payloads of 61.3, 45, and 12 short tons for the C-5, C-17, and C-130 respectively (AFPAM 10-1403, 2003:12). The block speeds listed in AFPAM 10-1403 that apply for distances between 2,001 and 2,500 NM were used (AFPAM 10-1403, 2003:13). These are 416 knots, 406 knots, and 272 knots. Hourly operating costs for fiscal year 2011 were obtained from Headquarters Air Force (HAF) (Appendix C). Where differences in operating cost occured between C-5A/B/C and C-5M or C-130E/H and C-130J aircraft, the lower number was used, in order to produce the most stringent target when calculating potential HA operating costs

Table 2. Summary of Conventional Airlift Specifications and Cost

Aircraft	Block Speed (knots)	Planning Payload (short tons)	Operating Cost (per hour)
C-5	416	61.3	$26,485
C-17	406	45	$11,658
C-130	272	12	$5,080

Sources: Block speed and payload capacity from AFPAM 10-1403 (2003).
Operating cost from HAF (fiscal year 2011).

Sealift Planning

Sealift payload capacity of a particular vessel is typically expressed in either square feet available or in number of TEUs that can be accommodated. Two generally accepted rules of thumb were used to convert these capacities into short tons. The results are shown in Table 9 in appendix D.

The first method of conversion used a standard estimate of 1 short ton per 20 square feet of cargo space. The second method translated number of TEUs to tons, based on approximations of typical container weights. The weight of a loaded TEU (including the container itself) can be as much as 26.5 short tons. A TEU holding ammunition will usually weigh 15 short tons. A TEU laden with water can weigh up to 10 tons, while one filled with food and other dry goods might only measure 6 tons (Montonye, 2010). Since HA/DR cargo does not usually include ammunition or water (but bottled water is *sometimes* sent to disaster areas), an average figure of 8 tons per TEU (average of 6 and 10) was used to convert number of TEUs to short tons.

The payload capacities of the US Army watercraft listed in Table 9 (Appendix D) were computed in a different manner. US SDDC data shows the JHSV can carry a typical load of 600 short tons. (This is in line with USTRANSCOM's assessment of the JHSV being capable of moving 1,000 short tons, but typically being space-limited to 600 short tons). SDDC also equates this 600 ST capacity to eight C-17 loads. Dividing 600 ST by 8 C-17s results in a load of 75 tons per C-17. While this is higher than the normal planning factor used by AFPAM 10-1403, it is within the capability of that aircraft. Therefore, a factor of 75 ST per C-17 was used to determine the equivalent tonnage capacity of the Army LSV ("24 C-17s") and LCU ("4 C-17s") (Sullivan, 2010).

Table 3 summarizes the main characteristics of the sealift vessels used in the LP model. Planning payload data were transferred from Table 9 (Appendix D). Speed and operating cost information were obtained from USTRANSCOM, Military Sealift Command (MSC), the US Navy official website, the US Congressional Budget Office (CBO), and Global Security.org. For all watercraft except JHSV, LSV, and LCU, the operating costs are typically expressed as daily rates. In order to compare these figures to airlift expenses, they were divided by 24 hours to obtain notional hourly operating costs. (For all vessels except US Army watercraft, these numbers were rounded to the nearest 100 dollar increment).

Both the hourly "prorated" and daily sealift costs are shown in Table 3. Using daily rates results in more expensive cost figures, since partial days are rounded up to the next whole day. However, this study used the less expensive hourly figures when injecting sealift cost data into the analysis. This had the added benefit of driving the target hourly operating costs for HA to lower (more conservative) values.

Table 3. Summary of Sealift Specifications and Cost

Vessel	Block Speed (knots)	Planning Payload (short tons)	Operating Cost (per day)	Operating Cost (per hour)
4,000 Containership	22	32,000	$84,000	$3,500
1,000 Containership	22	8,000	$56,000	$2,300
LMSR	19 24*	11,275	$80,000 $97,500*	$3,300 $4,000*
FSS	27 30 33*	1,800	$128,000 $142,000 $154,000*	$5,300 $5,900 $6,400*
RRF RORO	17	5,850	$65,000	$2,700
JHSV	35	600	$146,000	$6,100
Army LSV	11	1,800		$888
Army LCU	10	300		$459

*These speeds and cost figures were used in the LP model and cost analysis

Sources: Block speed and payload capacity from USTRANSCOM, US Navy official website, ASCAM 3.2a, US Congressional Budget Office (CBO), and GlobalSecurity.org. Operating cost data from USTRANSCOM and MSC.

Military Sealift Command provided daily operating cost information for LMSR and FSS, along with current charter rates for 4,000 and 1,000 TEU containerships (Clark, 2011). In the case of LMSR and FSS, the MSC "voyage calculator" Excel workbook was used to examine a range of operating costs for various speeds. The maximum speeds (24 knots for LMSR and 33 knots for FSS) were used in this scenario. This was based on the assumption that senior leaders would want the sealift vessels to move to Haiti as quickly as possible (particularly during the first few days of response time) (Clark, 2011). The highest operating speeds and expenses were also used in the LP model and cost analysis. (This was based on 24 knots for the LMSR and 33 knots for the FSS). However, the lower speeds and expenses are provided in Table 3 for use during follow-on missions when ship arrivals at Port au Prince would overlap. This would likely eliminate the need to operate at maximum (or near maximum) speed.

Activation and deactivation costs were not included in the LMSR, FSS, or RORO numbers. All daily operating costs in table 3 above are rounded up to the next highest $1,000 increment. No canal fees or war risk insurance were applied. Calculations do include costs for five total days in port (three days in CONUS, and two days in Port au Prince). Table 10 in appendix E details how the operating costs were determined for LMSR. Information for four classes of vessel (Shugart/Yano, Gordon/Gilliland, Watson, and Bob Hope) was obtained from the MSC "voyage calculator." For each speed value (19 knots and 24 knots), the four different operating expense values were averaged to determine a mean LMSR operating cost for that speed. The "voyage calculator" was also used to calculate FSS cost data for three different speeds (27 knots, 30 knots, and 33 knots).

USTRANSCOM confirmed the MSC RORO expense data, and provided estimated JHSV operating costs. Operating cost data for the JHSV was corroborated by the 597th Transportation

Brigade at Fort Eustis, Virginia. The 597th also provided hourly operating costs for the US Army LSV and LCU. (At their recommendation, the basic cost figures of $739.47 and $382.31 were increased by 20 percent to adjust for numbers that were five years old.) This resulted in hourly costs of $887.36 and $458.77 for the LSV and LCU. These numbers were then rounded up to the next highest dollar.

III. Methodology

Overview

Cargo requirements for Operation Unified Response were used to explore the utility of hybrid airships during intratheater HA/DR relief efforts. An excursion from the base scenario was employed, using a linear programming (LP) model. The model was used to determine the shortest time required to move a given weight of relief supplies from the CONUS to Port au Prince. The initial cargo requirement was set at 200 short tons per day. Several iterations of the model were performed, in order to account for the constraints imposed by limiting (or prohibiting) sealift or conventional airlift capacity. 50-ton HA were examined first, followed by 30-ton HA. Next, HA with variable payloads ranging from 31 tons through 49 tons were analyzed.

Then, operating cost data were injected to determine any efficiencies that might be gained for only minor time penalties. Parameters used for conventional airlift and sealift block speed, planning payload capacities, and operating costs were taken from Tables 1 and 2. A block speed of 80 knots was assumed for all HA.

Distance

In the actual operation, USTRANSCOM moved cargo from various locations in the United States to Haiti. The most frequently used seaport of embarkation was Jacksonville, Florida. The most common seaport of debarkation was Port au Prince (once it became operational) (USTRANSCOM, 2010:11). The most common air ports of embarkation and debarkation were Charleston, South Carolina, and Port au Prince, Haiti (Toussaint Louverture). (USTRANSCOM, 2010:6). The distance between Jacksonville and Port au Prince is approximately 878 nautical miles (NM) by air, and 891 NM by sea (AirRouting.com). The

distance between Charleston and Port au Prince is approximately 953 NM by air, and 956 NM by sea (SeaRates.com).

The longest expanse of 956 NM was chosen as a common distance requirement for sealift and airlift. This was done for two main reasons. All four distance values are within 10 percent of each other; they are not significantly different. This also provided one constant distance value to which the various modes of transport could be compared in the model.

Transport Mode Selection and Comparison

Several factors were considered when narrowing the type and number of transportation assets used for comparison with hybrid airships in this scenario. The island location of Haiti eliminated motor vehicles and railroads from consideration. Once the two modes of transportation were set to air and sea, the final point of aid distribution was considered. This was not examined in great detail in the LP model, or in this paper.

However, planners must take this into consideration. If distribution points are located a great distance from a conventional airport/runway, HA might be useful in moving cargo closer to them. Inland requirements for HA/DR cargo might also increase the need for HA (along with rotary wing aircraft) to transload cargo from seaports.

Data used in the LP model included current aircraft and ship payload capacities and speeds, daily lift requirements, and destination sea/air port conditions and capacity. The capabilities of the new JHSV were also considered. As mentioned previously, HA prototype payload capacity was constrained within minimum and maximum limits—30 and 50 ton. As used in this discussion, “conventional airlift” implies the use of C-5, C-17, or C-130 aircraft. “HA” is used to represent the use of hybrid aircraft.

Conventional Airlift

Comparing a notional 50-ton HA with organic USAF airlifters (based on AFPAM 10-1403), its planning payload of 50 tons is 76 percent greater than a C-130, 10 percent greater than a C-17, and 18 percent less than a C-5. The mean planning payload of the C-5 and C-17 is 53.2 short tons. The mean planning payload of the C-5, C-17, and C-130 is 40.8 short tons. Therefore, when comparing cargo-carrying capability of palletized relief supplies, a 50-ton (payload) HA can transport roughly the same amount as a fixed wing conventional airlifter selected from the AMC force. (Assuming C-5, C-17, and C-130 are all equally available to contribute to a particular operation.

To facilitate closer HA comparison to C-130 payloads, a notional 30-ton HA was also considered in this analysis. Recall that this payload weight was selected because it is the average of the proposed Sky Cat 20 and the Boeing-Skyhook HLV capacities (20 tons and 40 tons, respectively). A 30-ton HA would have 60 percent more capacity than a C-130, 33 percent less capacity than a C-17, and 51 percent less capacity than a C-5.

Conventional Airlift Exclusions

C-27J Spartan fixed-wing airlifters and CH-47 and CH-53 rotary wing aircraft were excluded from this analysis. This was chiefly due to their inability to travel from the CONUS to Haiti and back without refueling. (In this application, a one-way distance of 956 NM doubled yields 1912 NM total.)

The C-27J manufacturer lists an unrefueled range of only 1,000 NM with a 22,046 pound payload (approximately 11 short tons), and 2,300 NM with a 13,228 pound payload (6.6 ST) (Jackson, 2010:382). This lower limit of unrefueled range (1,000 NM with only 11 tons of payload) disqualifies the C-27J from further discussion in this particular scenario. C-27J Spartan

aircraft were also excluded because they are currently used in a US Army theater direct support apportioned role, and were not regularly employed in Operation Unified Response (VanHoof, 2011). CH-47 and CH-53 helicopters were also excluded from these calculations. The main reason for this is their limited range. Neither aircraft could have reached Port au Prince from Jacksonville or Charleston. The CH-47 is limited to a range of 1,260 NM, and only 651 NM when carrying a payload of 27,686 pounds (13.8 tons) (Jackson, 2010:711). The CH-53 can only reach a distance of 417NM, or 110 NM when carrying 27,204 pounds (13.6 tons) (Jackson, 2010:912).

Sealift

Sealift capacity far exceeds that of conventional airlift or near-term HA prototypes. Any one of the vessels used in this analysis can supply over 200 short tons of cargo in one trip. Because of this fact, one might be tempted to dismiss the impact of hybrid airships on sealift operations. However, because ship block speeds range from only one-eighth to one-half as fast as HA, there is a definite time advantage in using HA (and conventional aircraft) during the initial hours and days of HA/DR response.

Also, if a seaport is damaged and unusable for an extended period of time (as was the case in Port au Prince), air and ground transportation modes are especially vital to the relief effort. Or, a sea port may simply not exist (due to a poor economy or inland location). In the case of Haiti, limited model runs were performed to attempt to quantify the impact of sealift on the optimal use of HA during the initial response period.

The 4,000 TEU and 1,000 TEU vessels were used in this analysis because they represent the normal maximum and minimum capacity container ships used by MSC and the RRF (Gilbertson, 2011). LMSR, FSS, and RORO flesh out the reminder of the typical assets MSC

might use to move HA/DR cargo. Although the JHSV fleet is still being built, the speed (time) advantages of this ship compelled its inclusion in this study. Finally, the US Army LSV and LCU were added in the interest of completeness.

It should be noted that if the JHSV's full capacity of 600 tons is used, it is only capable of traveling 1200 nautical miles without refueling. However, when no cargo is carried, it can travel approximately 4700 NM (US Army, 2010:28). Using interpolation, (and assuming a linear relationship), if only 200 tons of cargo are moved, the JHSV could cover nearly 2400 NM (Appendix F). This represents adequate fuel capability to travel from the CONUS to Haiti and back with 200 tons of cargo onboard for the duration of the round trip.

Model Construction

This information was used to create a linear programming (LP) model in Microsoft Excel to minimize the total transit time from the CONUS to Haiti. Appendix H shows some examples of the Excel worksheet interface for the model. Tables 11 through 15 show the results of 54 runs of this model. The analysis was based on the following five basic situations: (1) all three modes of lift available (sealift, conventional airlift, and 50-ton HA), (2) no conventional strategic airlift platforms (C-5 and C-17) available, (3) no sealift available, (4) only C-130 and 30-ton HA available, and (5) only C-130 and HA (variable from 31-ton to 49-ton) available.

The main goal of the linear programming model was to minimize total transit time between the CONUS and Port au Prince, while still delivering at least 200 short tons of cargo. (However, an interesting characteristic must be noted. As long as the total cargo moved is greater than or equal to the daily requirement, the model does not necessarily advocate the use of a transport mode that can move more total cargo than another one.)

Excel's "solver" function was used to compute solutions. Each "run" of the model accounts for one day of movement. The model simply sums up the transit times for each shipment (if more than one) required to compile an aggregate of at least 200 short tons. *This is conservative, since it assumes that no two aircraft or ships are in transit simultaneously.* It also assumes that the total daily number of missions from Charleston to Port au Prince is less than the number of aircraft/ships useable. However, it also provides good transparency into the operation, and allows for quick estimates of "worst case" timelines required.

The model is simple enough that planners can manually plot the transit times and cargo amounts provided by the model to create multiple overlapping or independent movement timelines to suit the operational conditions. A notional example of this is provided in Appendix G. It is also discussed in the "Conclusions and Recommendations" section of this study.

The primary focus of this analysis was moving payloads in one direction only; from the CONUS to Haiti. Therefore, productivity factors were not used (all sorties were assumed to have a load on board). Mission capable (MC) rates were included in the model to enable future analysis using actual number of aircraft or ships available. The model receives the "number available" as a user input. This figure is then multiplied by the mission capable rate to determine the "number useable." Mission capable rates for C-5 and C-17 aircraft (0.75 and 0.90, respectively) were mirrored from the AMC Mobility Planner's Calculator (AMPCALC) spreadsheet model (version dated 23 November 2010). A mission capable rate of 0.90 was assumed for the C-130 and hybrid airships.

Sealift MC rates were assumed to be "1.0." For this scenario of moving only 200 tons of cargo, this simplified the analysis. Because only one ship/boat is needed to move all 200 tons,

using a MC rate of "1" simulated TRANSCOM and MSC tasking only one vessel per day that was in ready status in port (considered by the model as "relatively" easy to assure).

In order to prevent the model from unintentionally limiting the use of a particular ship or airframe, relatively large values were originally inserted into the LP model's "number available" input fields. For example, the number nine was initially used for all sealift assets, the C-5, the C-17, and all HA. This notional figure was chosen because even with maintenance reliability rates of 0.75 or 0.90, this resulted in a "number useable" of six or eight. This value was high enough to ensure that any one type of surface vessel, strategic airlifter, or HA could initially carry the entire 200 tons of daily cargo. Likewise, the number 29 was used for the C-130; to ensure 17 C-130s were initially able to carry the entire allotment of cargo.

As the analysis progressed, the numbers of sealift platforms and large aircraft "available" (independent variables) were reduced to determine the number of smaller airlifters (C-130 and HA) tasked with cargo missions to Haiti (dependent variables). This was done to force the model to move some of the cargo on a craft with smaller payload capability and/or slower speed. Eventually, "head-to-head" comparison of the C-130 and hybrid aircraft required manipulating the "number available" of both airframes. The end result was an analysis of where HA could be useful within the spectrum of lift capabilities.

The following variables were used in the LP model:

Conventional Airlift:
A_1 = C-5
A_2 = C-17
A_3 = C-130

Hybrid Airships:
HA_1 = 30-ton payload hybrid airship
HA_2= 50-ton payload hybrid airship
HA_3= Variable from 31-ton to 49-ton payload hybrid airship

Sealift:
S_1 = 4,000 container ship
S_2 = 1,000 container ship
S_3 = Large, medium speed roll-on, roll-off (RORO) (LMSR)
S_4 = Fast sealift ship (FSS)
S_5 = Ready Reserve Force (RRF) RORO
S_6 = Joint high speed vessel (JHSV)
S_7 = Army logistics support vessel (LSV)
S_8 = Army landing craft utility (LCU)

Other Variables:
M = Number of missions, or “trips” required for a particular aircraft or vessel to meet its share of the daily cargo demand (if that aircraft or vessel was used in the optimized solution)
T = Time (in hours) to travel from POE to POD.
Calculated by dividing distance (in NM) by aircraft or ship block speed (in knots).
P = Planning payload capacity
V = Number of particular aircraft or ships available for use
MC = Mission capable rate for a particular aircraft or ship
U = Number of particular aircraft or ships useable. Calculated as: V x MC
Q = Daily cargo requirement (“quota”) (short tons)

The LP model minimized the following objective function (Ragsdale, 2008:38):

$$(MA_1 \times TA_1) + (MA_2 \times TA_2) + (MA_3 \times TA_3) + (MHA_1 \times THA_1) + (MHA_2 \times THA_2) + (MHA_3 \times THA_3) + (MS_1 \times TS_1) + (MS_2 \times TS_2) + (MS_3 \times TS_3) + (MS_4 \times TS_4) + (MS_5 \times TS_5) + (MS_6 \times TS_6) + (MS_7 \times TS_7) + (MS_8 \times TS_8)$$

The Excel solver selections for “assume linear model” and “assume non-negative” were also enabled. Additionally, the LP was subject to the following constraints (Ragsdale, 2008:26):

(1) $PA_1 + PA_2 + PA_3 + PHA_1 + PHA_2 + PHA_3 + PS_1 + PS_2 + PS_3 + PS_4 + PS_5 + PS_6 + PS_7 + PS_8 \geq Q$

(2) $M \leq U$

(3) M = Integer

Model Implementation

Optimal Intratheater Mix

The LP model was used in the sequence shown below, consisting of five main steps.

(1) **All Three Modes Available (Sealift, Conventional Airlift, and HA)**

(1a) C-5 “number available” = 9
C-17 “number available” = 9
C-130 “number available” = 29
30-ton HA “number available” = 0
50-ton HA “number available” = 9
Variable payload HA “number available” = 0
Each sealift ship “number available” = 9

(1b) C-5 “number available” = 0
C-17 “number available” = 9
C-130 “number available” = 29
30-ton HA “number available” = 0
50-ton HA “number available” = 9
Variable payload HA “number available” = 0
Each sealift ship “number available” = 9

(2) **No Conventional Strategic Airlift Platforms Available (No C-5 or C-17)**

C-5 “number available” = 0
C -17 “number available” = 0
C-130 “number available” = 29
30-ton HA “number available” = 0
50-ton HA “number available” = 9
Variable payload HA “number available” = 0
Each sealift ship “number available” = 9 (initially)

Sealift ship “number available” then set = 0 incrementally (one vessel at a time) after each of the first five model runs to determine the hierarchy of the best sealift solution

(3) **No Sealift Available**

Each sealift ship “number available” = 0

(3a) C-5 “number available” = 9 (initially)
30-ton HA “number available” = 0
50-ton HA “number available” = 9
Variable payload HA “number available” = 0

Number of C-5 aircraft incrementally decreased. For each decrement in the number of C-5 aircraft available, three separate cases were tested:

(i) Setting C-17 “number available”=9, and C-130 “number available”=29
(ii) Setting C-17 “number available”=0, and C-130 “number available”=29
(iii) Setting C-17 and C-130 “number available” = 0

(3b) C-5 “number available” = 0
C-17 “number available” = 9 (initially)
C-130 “number available” = 29
30-ton HA “number available” = 0
50-ton HA “number available” = 9
Variable payload HA “number available” = 0
Number of C-17 aircraft incrementally decreased

(3c) C-5 “number available” = 0
C-17 “number available” = 0
C-130 “number available” = 29
30-ton HA “number available” = 0
Variable payload HA “number available” = 0
50-ton HA “number available” = 9 (initially) (“number useable” = 8)
Number of 50-ton HA incrementally decreased

(4) **Incremental Analysis of C-130 and 30-Ton HA**

C-5 “number available” = 0
C-17 “number available” = 0
C-130 “number available” = 29
30-ton HA “number available” = 0 (initially)
50-ton HA “number available” = 0
Variable payload HA “number available” = 0
Each sealift ship “number available” = 0
Number of 30-ton HA incrementally increased from 0 through 9

(5) **Sensitivity Analysis of C-130 and HA (31-Ton to 49-Ton HA)**

C-5 “number available” = 0
C-17 “number available” = 0
C-130 “number available” = 29
30-ton HA “number available” = 0
50-ton HA “number available” = 0
Variable payload HA “number available” = 9
Variable payload HA “capacity” = 49 tons (initially)
Each sealift ship “number available” = 0
Payload capacity of HA decreased incrementally from 49 tons through 31 tons.

Sensitivity analysis was not used in comparing all potential combinations for the iterations of this LP model. This was chiefly due to the incompatibility of Excel sensitivity analysis with model parameters constrained as integers. Put simply, the number of aircraft or ships used in the model was set to an integer value, since only entire vessels fly or sail—not portions of them. In the interest of completeness, these values were temporarily allowed to compute as non-integer values, to enable Microsoft Excel's sensitivity analysis function. The resulting computations were not analytically useful. Consequently, several manual runs of the LP model had to be performed, with the number of lift assets changed manually for each iteration.

Initial results from step three showed interesting relationships between HA and C-130 payloads. Therefore, steps four and five were designed specifically to compensate for the limitations of the LP model and Excel's sensitivity analysis. Step four was an incremental comparison between the number of C-130 aircraft and 30-ton payload HA that might be used to move the 200 ton daily cargo requirement from Charleston to Port au Prince. Step five was similar to a sensitivity analysis, and was used to compare C-130 and HA. The HA payload was changed in increments of 1 ton, using a range of 31 to 49 tons. The C-130 payload was held constant at 12 tons.

Cost

Hourly cost data were also used to calculate the expense of moving cargo to Haiti via conventional airlift and sealift. The basic approach was to first identify any conventional airlift sorties that could be eliminated ("saved") by using HA. The model multiplied the total number of conventional airlift missions by mission time in hours (Charleston to Port au Prince). This

figure was then multiplied by the hourly operating cost. As the number of conventional airlifters used was reduced, the number of HA used increased. This resulted in a potential airlift "cost difference" savings.

This total operating cost saved was then divided by the total number of HA hours flown by the model. This computation generated maximum HA "break-even" costs. If HA can be operated at less expense than these figures, they will potentially be more cost-efficient than conventional airlift in some cases.

The same process was then used to compare HA and sealift, and generate maximum HA "break-even" operating costs. This comparison was more straightforward, since only 50-ton payload hybrid airships were compared to sealift platforms. The potential cost benefit of simultaneously launching HA and sealift was also considered, and is detailed in the "Sealift Cost Analysis" section.

Because the priority was placed on timely movement of the payloads ***to*** Port au Prince, the total time spent airborne or at sea was only calculated for that direction of travel. In order to accurately reflect total costs associated with this movement, the cost values from the model would have to be multiplied by a factor of two. However, that calculation is not necessarily pertinent to the discussion at hand. The calculation of interest, however, is the potential cost *difference* between various combinations of the three modes.

IV. Analysis

Optimal Intratheater Mix

The initial result of step one of the model run (all transport modes available) favored using four C-5 aircraft to move all the cargo. This option required 9.2 hours of total flight time from the CONUS to Haiti, and could move 245.2 tons of materiel. The number of C-5 aircraft available was then set to zero, and the model was run again. The revised solution used five C-17 sorties to move all the cargo. This option required 11.8 hours of total flight time from the CONUS to Haiti, and could move 225 tons of materiel. These results are listed in Table 11 (Appendix I).

In step two (with C-5 and C-17 airlift unavailable), six iterations of model runs were performed. Initially, all sealift asset "number available" values were set to "9." After the first optimal solution was determined, the "number available" for that particular vessel type was set to "0," and the model was re-run to determine the "next best" solution. The first five model runs identified only one sealift vessel that would notionally be used to move all the daily cargo required.   The sixth (final) iteration bypassed RORO, Army watercraft, and the C-130 (eight aircraft "useable") in favor of 50-ton hybrid airships. These results are listed in Table 12 (Appendix I).

The optimal sealift solution involved using only one JHSV. This would require over a day (27.3 hours), and could move up to 600 tons of cargo. During the subsequent model run—if no JHSV were available ($S_6 = 0$)—the next best solution was one FSS. This option could transport roughly 1,800 tons of cargo in 29 hours. (It is worth noting that the LP model chose the JHSV before the FSS, even though it can move only one-third as much payload. This is due

to the *slight* advantage of 1.7 hours less enroute time. If the FSS speed were reduced from 33 knots to 27 knots, its movement would require 35.4 hours—a more significant time difference.)

The next best option was the use of one LMSR (39.8 hours and 11,275 tons). The 4,000 container ship was prioritized fourth (43.5 hours and 32,000 tons), and the 1,000 container ship placed fifth (43.5 hours and 8,000 tons).

A sixth iteration of the model resulted in the RORO, C-130, and US Army vessels (LSV and LCU) being bypassed (unused) in favor of four 50-ton hybrid airships (“HA_2”). This option could carry 200 tons of cargo in 47.8 hours, using four 50-ton HA sorties.

Once again, this result demonstrates a limiting characteristic of the LP model used in this study. Note that one RORO could transport 5,850 tons in 56.2 hours—at a speed of 17 knots. A loss of only 8.4 hours of transit time would allow 5,650 tons more cargo to be moved than with four 50-ton HA. To illustrate the sensitivity of speed changes on the model, this iteration was run again using a RORO speed of 22 knots (the same RORO speed used by ASCAM 3.2). The resulting solution prioritized RORO over HA, C-130, LSV, and LCU. In that case, one RORO could move 5,850 tons to Haiti in 43.5 hours.

This next phase of the analysis (step three) was designed to examine the interaction between conventional airlift and 50-ton hybrid aircraft, while isolating the effects of sealift (no sealift available). It was conducted in three sub-sections, using a total of 19 model runs. These sub-sections analyzed the use of C-5, C-17, C-130, and 50-ton HA; C-17, C-130, and 50-ton HA (no C-5s); and C-130 aircraft and 50-ton HA (no C-5 or C-17 aircraft), respectively. The results are shown in Table 12 (Appendix I).

The goal of the first subsection was to ascertain where 50-ton HA could be used in the overall airlift mix. This subsection used the C-5 as the main independent variable. The number

of 50-ton HA available was held constant at nine. The number of C-5 and C-17 aircraft available was initially set to nine. The number of C-130 aircraft available was initially set to 29. The first run produced the same solution as in step one (4 C-5s were used). Then, the number of C-5 aircraft available was incrementally decreased, to produce "number useable" values of three, two, and one. For each decrement in the number of C-5 aircraft, three cases were tested. First, the model was run with C-17 and C-130 "numbers available" held at 9 and 29, respectively. Then, the C-17 "number available" was set to zero, and the C-130 "number available" was held at 29. Finally, both the C-17 and C-130 "number available" values were set to zero.

The second part of step three involved isolating C-5 aircraft from the analysis ("number available" = 0), while measuring the effects of incrementally reducing the C-17 availability on the mix of C-17, C-130, and 50-ton HA. The final part of step three removed sealift, C-5, and C-17 aircraft from the analysis, and incrementally decreased the number of 50-ton HA available. This was done to determine the optimal mix of 50-ton HA and C-130 aircraft.

Results

Tables 11 through 13 (Appendix I) show the results of the analysis for steps one, two, and three. The first overall conclusion is that if a combined total of four C-5 and/or C-17 aircraft are useable, using 50-ton HA to move 200 tons of cargo is not time-effective. However, if only three or fewer C-5 aircraft are useable, C-130s are available, and no C-17s are available, then one, two, or three 50-ton HA can be useful to the relief effort. Likewise, if no C-5s are available, three or fewer C-17s are useable, and C-130s are available, up to three 50-ton HA will also help minimize the cargo's enroute time.

Most striking, however, was the relationship between C-130 and 50-ton HA when no C-5 or C-17 aircraft were available. If four 50-ton HA were useable, then 200 tons of cargo could be

moved in just under 48 hours without the use of C-130s. As the number of useable 50-ton HA was decreased incrementally from four to three, five C-130 sorties were needed to make up the difference. Each successive subtraction of one HA required four more additional C-130s to move at least 200 tons of cargo. Eventually, if only C-130 aircraft were used to airlift the cargo (no HA available), this only increased the total flying time by 12 hours—but it required 17 sorties.

The fourth and fifth steps in the analysis involved a more detailed comparison of the C-130 and a notional HA capable of moving less than 50 tons of cargo. This was done to gain more information about the correlations between notional HA and C-130 aircraft that were uncovered in step three. A smaller HA was used for this more detailed comparison, since its payload capacity would be more similar to the C-130 planning cargo weight of 12 tons—and therefore allow for more fidelity. This permitted the model to demonstrate the sensitivity involved in increasing or decreasing the number of useable C-130s or hybrid airships by increments of one.

In step four, a notional constant HA payload capacity of 30 tons was used (represented by "HA_1" in the LP model). The results are listed in Table 14 (appendix I). The number of 30-ton HA "available" was held constant at nine (producing eight 30-ton HA "useable"). This number was chosen because it is greater than the seven 30-ton HA that are required to transport at least 200 tons of cargo. The number of C-130 aircraft "available" was initially set to 29 (producing 26 C-130 aircraft "useable"). Recall that this artificially high number was chosen because it is much greater than the 17 C-130 sorties that are required to transport at least 200 tons of cargo. Eight model runs were performed. After each iteration, the number of C-130 aircraft available

was decreased to produce a number of “useable” aircraft for the upcoming run that was one less than the number required for the current solution.

The first model iteration (predictably) resulted in 17 C-130 sorties required to move the cargo. This was due to the speed advantage (greater than 3:1) of the C-130 over the HA. This solution could take up to 59.8 hours, and move 204 tons of materiel. The number of C-130 aircraft was then set to 18 (giving 16 “useable”). This produced a solution that used 15 C-130s and one 30-ton HA (64.7 hours and 210 tons of cargo). The analysis continued in this fashion until the number of C-130 aircraft “useable” was zero, and the number of 30-ton HA required was seven (83.7 hours and 210 tons of cargo).

A clear pattern emerged; every other increase in the number of HA by one (i.e. a total of one, three, five, and seven HA) corresponded to a decrease of two C-130s used. The alternating incremental increases in HA used (HA total of two, four, or six) caused a decrease of three C-130 sorties required. Based on the limited, simple analysis performed here, an initial rule of thumb is that one 30-ton HA mission can substitute for 2.5 C-130 sorties. This can be further supported by the fact that 12 tons (C-130 planning payload) times 2.5 equals 30 tons.

While this is straightforward mathematics, a second relationship involving time can also be drawn from this analysis. When considering the use of 30-ton capacity hybrid airships, the best compromise between time and assets used seems to occur when four HA and seven C-130 sorties are employed. This only increases the total flight time by 12.6 hours (from 59.8 hours to 72.4 hours), but reduces the number of C-130 sorties by 58.9 percent; from 17 to 7. (This is in comparison to the 23.9 hour difference between using 17 C-130 missions (and zero HA) and zero C-130 (and seven HA missions). This 23.9 hour difference was obtained by subtracting 59.8 hours from 83.7 hours).

Step five explored the relationship between HA and C-130 payload weight even further. The goal of this analysis phase was to determine how HA payload weights between 30 and 50 tons might affect a mix of hybrid airships and C-130s. Nineteen runs of the LP model were used. The C-130 payload weight was held constant at 12 tons, while the HA payload was incrementally reduced by one ton, from 49 tons to 31 tons (using "HA_3"). The number of C-130 aircraft "available" was set to 29 (giving 26 "useable"), and the number of HA "available" was set to 9 (giving 8 "useable"). All other modes of airlift (and all modes of sealift) were set to zero available.

The results of this analysis are shown in Table 15 (Appendix I). The solution requiring the least amount of time to carry the most cargo used four 49-ton HA sorties and one C-130 mission. This option moved 208 tons of cargo in 51.3 hours of flight time. This represents a decrease (improvement) of 8.5 hours of time from the fastest solution from step four (59.8 hours). It also moved four more tons of cargo. However, the most significant difference is the use of only five total sorties, as opposed to the 17 sorties required in step four's quickest combination. (The number of C-130 sorties decreased from 17 to one, and the number of HA sorties increased from zero (30 ton payload) to four (49 ton payload)).

At the other extreme, using hybrid airships to move payloads between 31 and 40 tons did not trigger the use of *any* HA. In this payload range, the optimal (minimum time) solution matched that obtained with the 30-ton HA in step four (17 C-130s, zero HA, 59.8 hours, and 204 tons of cargo).

However, a dramatic change occurred between the 40-ton and 41-ton HA payload analysis. A combination of four 41-ton HA sorties and three C-130 sorties were able to meet the 200 ton requirement *exactly*, in 58.3 hours of flight time. If 42-tons were moved on each HA,

the theoretical optimal solution used five HA and zero C-130s to move 210 tons in 59.8 hours. As the HA payload increased into the 43-ton to 49-ton range, the LP model consistently selected four HA. The number of C-130 sorties varied between one and three. The amount of cargo moved ranged from 200 to 208 tons, and the total flight time was estimated between 51.3 and 58.3 hours.

Summary of Results

This five step analysis was used to define the upper and lower limits of effectiveness versus efficiency for HA used to assist in moving 200 tons of HA/DR cargo per day. The results of steps one and two are fairly straightforward, and are shown in Tables 11 and 12 in Appendix I. Table 4 (following page) summarizes the results of the LP model runs from steps three through five (Tables 13, 14, and 15 in Appendix I) for a mix of HA and conventional airlifters. The highlighted rows indicate some of the more interesting relationships between lift mix and time required. This should help guide a reader's eyes to those particular rows, and the ones immediately adjacent to them.

Table 4. Summary of Conventional Airlift and HA Mix to Move 200 Short Tons

C-5	C-17	C-130 (12 ST Payload)	Number of HA	HA Payload Weight (ST)	Total Flight Time (hrs)	Total Cargo (ST) (rounded to nearest ST)
4	0	0	0	-	9.2	245
3	1	0	0	-	9.3	229
3	N/A	2	0	-	13.9	208
3	N/A	N/A	1	50	18.8	234
2	2	0	0	-	9.3	213
2	N/A	3	1	50	27.1	209
2	N/A	N/A	2	50	28.5	223
1	4	0	0	-	11.7	241
1	N/A	0	3	50	38.1	211.3
N/A	5	0	0	-	11.8	225
N/A	4	2	0	-	16.4	204
N/A	3	2	1	50	26.0	209
N/A	2	1	2	50	32.1	202
N/A	1	1	3	50	41.7	207
N/A	N/A	0	4	50	47.8	200
N/A	N/A	5	3	50	53.4	210
N/A	N/A	9	2	50	55.5	208
N/A	N/A	13	1	50	57.6	206
N/A	N/A	17	0	-	59.8	204
N/A	N/A	1	4	49	51.3	208
N/A	N/A	1	4	48	51.3	204
N/A	N/A	1	4	47	51.3	200
N/A	N/A	2	4	46	54.8	208
N/A	N/A	2	4	45	54.8	204
N/A	N/A	2	4	44	54.8	200
N/A	N/A	3	4	43	58.3	208
N/A	N/A	0	5	42	59.8	210
N/A	N/A	3	4	41	58.3	200
N/A	N/A	17	0	40	59.8	204
N/A	N/A	17	0	39	59.8	204
N/A	N/A	17	0	38	59.8	204
N/A	N/A	17	0	37	59.8	204
N/A	N/A	17	0	36	59.8	204
N/A	N/A	17	0	35	59.8	204
N/A	N/A	17	0	34	59.8	204
N/A	N/A	17	0	33	59.8	204
N/A	N/A	17	0	32	59.8	204
N/A	N/A	17	0	31	59.8	204
N/A	N/A	17	0	30	59.8	204
N/A	N/A	15	1	30	64.7	210
N/A	N/A	12	2	30	66.1	204
N/A	N/A	10	3	30	71.0	210
N/A	N/A	7	4	30	72.4	204
N/A	N/A	5	5	30	77.3	210
N/A	N/A	2	6	30	78.7	204
N/A	N/A	0	7	30	83.7	210

Source: Author

Table 4 demonstrates the airlift effectiveness that can be gained by using up to five hybrid airship sorties to move 200 tons of cargo from Charleston to Port au Prince. If strategic airlift assets are available (and the destination airfield can receive them), the daily requirement for HA sorties can likely range from zero to three. If only C-130 aircraft and HA are used, the best compromise between speed and number of sorties (and assets) required is through the use of one to three C-130 flights and up to four HA sorties per day. In this scenario, this assumes HA cargo weights between 41 and 50 tons, and C-5, C-17, and C-130 planning payloads from AFPAM 10-1403.

Cost Analysis

This phase of analysis determined the maximum hourly operating cost for the three notional types of hybrid aircraft; 50 ton payload, 30 ton payload, and HA carrying payloads between 31 and 49 tons. The underlying assumption was that if HA costs are equal to or greater than other lift modes (and no time benefit or closer POD is gained), then HA use may not be beneficial.

The cost benefit of using fewer conventional airlifters was first used to derive a maximum “break-even” hourly operating cost for each type of HA. The same concept was used to compare 50-ton HA and sealift platforms. Finally, the maximum HA “break-even” operating costs for conventional airlift and sealift were compared. Cost per ton-mile (or million ton-mile) per day comparisons were not used in this analysis. This was done because the emphasis was on speed first, then cost savings. As a result, hourly operating costs proved more useful in this case. Recall also that these operating costs are based on one-way movement from the CONUS to Haiti only.

Airlift Cost Analysis

This analysis began by determining the five most costly conventional airlift cases examined in the preceding section. These were all based on using zero HA. As the number of HA used increased, the number of conventional airlifters decreased. This resulted in lower operating costs due to fewer airlifters flying. This cost difference was used to determine a maximum "break-even" hourly operating cost for HA. The following equation was used:

$$Maximum\ HA\ hourly\ cost = \frac{Difference\ in\ Airlift\ Cost}{Number\ of\ HA\ used\ x\ 12\ hours} \qquad (1)$$

The "12 hours" value accounts for the length of time required for one HA to travel the 956 nautical miles from Charleston to Port-au Prince at 80 knots. The maximum HA hourly cost was re-computed for each incremental increase in number of HA used (one, two, three, four, and five).

The results of these calculations are shown in Tables 16, 17, and 18 in appendix J. (The basic data used to construct these tables (number of airframes employed) was copied from Tables 13, 14, and 15 in Appendix I.) Conventional airlift and sealift operating costs were calculated by the LP model. Table 5 (following page) summarizes the "break-even" hourly operating costs for the three types of HA. The lowest numbers represent the most challenging targets to meet. The highest numbers in each case are also provided to give some context to the acceptable range of HA hourly operating costs.

Table 5. Summary of Hybrid Airship / Airlift "Break-Even" Operating Costs

Conventional Airlifter	HA Payload	Maximum Conventional Airlift Cost (Charleston to Port au Prince)	Lowest HA "Break-Even" Hourly Cost	Highest HA "Break-Even" Hourly Cost
C-5	50 ton	$243,458	$5,072	$5,680
C-17	50 ton	$145,513	$2,288	$3,032
C-130	50 ton	$303,530	$5,952 (various combinations)	$6,324 (0 x C-130 / 4 x HA)
C-130	30 ton	$303,530	$2,976 (15 x C-130, 1 x HA)	$3,720 (various combinations)
C-130	41-49 ton	$303,530	$5,059 (0 x C-130, 5 x HA) Next lowest: $5,208 (3 x C-130, 4 x HA)	$5,952 (1 x C-130, 4 x HA)

Source: Author

In the case of the C-130 and 30-ton HA comparison, the lowest notional HA operating cost was $2,976 per hour (Appendix J, Table 17). However, this occurred when 15 C-130s were used, but only one HA was employed. The next highest HA "break-even" allowable operating cost ($3,472) represents an increase of nearly 500 dollars per hour, and occurred when 10 C-130s and three HA were used. The highest "break-even" cost of $3,720 occurred in three instances (combinations), and required between two and twelve C-130s, while using two to six 30-ton HA.

The "break-even" operating costs associated with HA payloads between 31 and 49 tons (compared against C-130 loads) ranged from $5,059 to $5,952 (Appendix J, Table 18). An intermediate "break-even" HA operating cost of $5,208 per hour represents a nearly even mix of C-130s (three aircraft) and HA (four HA carrying either 41 or 43 tons of payload). It is significant to note that using just one C-130 boosted the allowable operating cost of the HA by almost $900 per hour (from $5,059 to $5,952). Table 15 in appendix I also shows that using one

C-130 and four HA (carrying payloads of 47 to 49 tons) required the least amount of total transit time for all the variable-payload HA / C-130 comparisons.

These numbers also show that 50-ton HA hourly operating costs must be held lowest ($2,288 to $3,032 per hour) when they are used in combination with C-17s. When HA are limited to payloads of 30 tons, and used in combination with C-130 airlift, the allowable HA costs only increase slightly, to a range of $2,976 to $3,720 per hour. However, when HA are used to transport payloads between 41 and 50 tons, their allowable hourly operating costs increase to a range between approximately $5,000 and $6,000 (when compared to C-130s). Due to the high operating expenses of the C-5 aircraft, 50-ton HA can augment them, and also be financially beneficial at hourly costs of up to $5,680.

Sealift Cost Analysis

This notional HA operating cost data was then compared to sealift expenses. Factors such as total transit time, expected duration of the operation, daily tonnage requirements, and all actual transportation assets available (sea and air) all factored into this analysis. However, this assessment began with a simple comparison of cost per hour to meet the minimum requirement to transport 200 tons of cargo 956 nautical miles.

When comparing HA with sealift, the LP model determined that one JHSV, one FSS, one LMSR, or either container ship (4,000 and 1,000 TEU) could move more payload in less total transit time than four 50-ton hybrid airships (The four HA would each require 12 hours to travel from the CONUS to Port au Prince, for a sum total of 48 hours of travel time. Reference Appendix I, Table 12). This does disregard the potential benefit of using one or two HA sorties to start the flow of materiel into the area before the ships arrive. It also assumes (very

conservatively) that no more than one HA can be airborne from Charleston to Port au Prince at one time.

Recall that the daily operating costs for sealift vessels were "pro-rated" into hourly costs in Table 3. The basic equation from the airlift-HA cost comparison section above was modified to read as follows:

$$Maximum\ HA\ hourly\ cost = \frac{Prorated\ Hourly\ Sealift\ Cost}{Number\ of\ HA\ used\ x\ 12\ hours} \qquad (2)$$

This equation was then used to determine the "break-even" HA costs compared to these five types of sealift vessels. Table 6 shows the results of these calculations. The last three rows illustrate the higher "break-even" HA costs possible if only two airships were used to augment the initial flow of sealift. (As expected, using half the number of HA doubles the allowable "break-even" hourly operating costs, since the number of sealift assets remains constant at one).

Table 6. Summary of Hybrid Airship / Sealift "Break-Even" Operating Costs (Computed From Prorated Hourly Sealift Costs)

Sealift Vessel	Sealift Cost (Charleston to Port au Prince)	Total Sealift Time (hours) (Charleston to Port au Prince)	Number of 50-ton HA	Total HA Time (hours) (Charleston to Port au Prince)	HA "Break-Even" Hourly Cost
1 x JHSV	$166,530	27.3	4	48	$3,469
1 x FSS	$185,600	29.0	4	48	$3,867
1 x LMSR	$159,200	39.8	4	48	$3,317
1 x 4,000 Container	$152,250	43.5	4	48	$3,172
1 x 1,000 Container	$100,050	43.5	4	48	$2,084
Use of only 2 x 50-ton HA to augment initial sealift flow:					
1 x JHSV	$166,530	27.3	2	24	$6,939
1 x FSS	$185,600	29.0	2	24	$7,733
1 x LMSR	$159,200	39.8	2	24	$6,633

Source: Author

While these are simplistic calculations, they do show that if HA operating costs can be maintained below $3,172 per hour, four 50-ton HA can transport 200 tons of cargo 956 nautical miles in just 4.5 hours less than a 4,000 container ship. Additionally, the last three rows of Table 6 address the use of two HA to augment the flow of materiel during the first 24 hours of sealift transit. (This solution would potentially deliver only 100 tons of cargo in the first 24 hours from APOE departure, but would result in more than 200 tons arriving at the APOD within 48 hours—in two cases the JHSV and FSS would arrive in less than 30 hours.)

In order to give more clarity to the HA / sealift cost comparison, daily sealift costs were re-introduced. Because the total "HA-only" flight time in this scenario was 48 hours (to deliver 200 tons), this figure can be compared relatively easily to the two-day operating cost of sealift. The same daily sealift costs from table Y in section II (literature review) and appendix B were used. US Army LSV and LCU were not included in the daily cost comparison, since their operating expenses (like airlift) are calculated on an hourly basis.

The following equation was used to compute the maximum HA hourly "break-even" cost from basic daily sealift operating expenses:

$$Max\ HA\ hourly\ cost = \frac{Daily\ Sealift\ Cost\ x\ 2\ days}{4\ HA\ x\ 12\ hours} = \frac{Daily\ Sealift\ Cost\ x\ 2\ days}{48\ hours} \qquad (3)$$

Because the RORO requires between two and three days of enroute time (56.2 hours), its daily operating cost was multiplied by three (instead of two). Table 7 shows the results of these calculations.

Table 7. Hybrid Airship / Sealift "Break-Even" Operating Costs (Computed From Basic Daily Sealift Costs)

Sealift Vessel	Daily Sealift Cost (Charleston to Port au Prince)	Daily Sealift Cost x 2 (or 3) Days	HA "Break-Even" Hourly Cost
2 Days Enroute			
1 x JHSV	$146,000	$292,000	$6,083
1 x FSS	$154,000	$308,000	$6,417
1 x LMSR	$97,500	$195,000	$4,063
1 x 4,000 Container	$84,000	$168,000	$3,500
1 x 1,000 Container	$56,000	$112,000	$2,333
3 Days Enroute			
1 x RORO	$65,000	$195,000	$4,063

The most significant difference between using "hourly" (prorated) and daily sealift expenses to compute HA "break-even" costs occurs when comparing the JHSV and FSS. These allowable HA "break even" costs nearly doubled from approximately $3,500 per hour to roughly $6,000 per hour. When considered as a group, the remaining comparisons (LMSR, container ships, and RORO) all stayed within the same approximate $2,000 to $4,000 per hour range. Overall, this confirms that the prorated "hourly" sealift cost targets are more challenging (conservative) for the HA to meet.

V. Conclusions and Recommendations

Summary of Conclusions

Hybrid airships can be used to effectively and efficiently augment USTRANSCOM's current airlift and sealift capability. Specifically, for medium-range intratheater distances (approximately 2,500 nautical miles one way), HA can help reduce or even minimize the total time required to move humanitarian and disaster relief assistance to the area of need. Based on a daily requirement of 200 tons of cargo, as many as five HA (each capable of lifting 40 to 50 tons of payload) can be useful in moving supplies to coastal locations (or some landlocked areas). This assumes C-5, C-17, and C-130 planning payloads are in accordance with AFPAM 10-1403. It also assumes that there are no significant obstacles or headwinds on the intended flight path that would necessitate HA speeds in excess of 80 knots, or require them to climb higher than 10,000 feet.

Strategic airlift assets can move HA/DR cargo in the shortest amount of time. If four or more total C-5 / C-17 missions are possible in one day, the use of hybrid airships may not be beneficial (although some financial savings may be realized). However, if three or fewer C-5 / C-17 aircraft are at a commander's disposal, then the use of up to three 50-ton HA can fill this gap in capability.

If no strategic airlift assets are available, then each HA mission (capable of lifting 41 to 50 tons) can feasibly replace three to four C-130 sorties. In the scenario described here, a good compromise of time and assets used results from using four HA and up to three C-130 missions. This minimizes the number of airframes used, and could gain at least 12 hours in closure time. (This total closure time could be even better (lower) if HA missions can be overlapped). 30-ton

HA can be useful, but based on this analysis, keeping the number of C-130 sorties less than or equal to three requires six HA, and could increase the closure time by 25 hours.

HA can also be used to supplement sealift. This is especially important during the opening days of an operation, while ships are being readied, loaded, or starting their voyage. Assuming HA operations require 12 hours from notification to launch, the first HA could arrive two to three days before the first ships (Appendix G). This suggests that the niche HA capability for long-lasting operations that use sealift will likely be concentrated within the opening week (for intratheater distances).

Based on fiscal year 2011 operating costs, if expenses for hybrid airships can be held below $3,000 per hour, they will likely be more efficient to operate than the C-17. If small cargo totals (i.e. 200 tons) must be moved as quickly as possible (and/or while sealift is in transit), then HA operating costs of $3,000 per hour or less also make them an economical option compared to sealift. In comparison to C-5 and C-130 aircraft, HA "break even" operating costs might be as high as $5,000 per hour.

Recommendations

HA Fleet Size and Composition

The US Department of Defense can leverage commercial technology and development of hybrid airships to its advantage. By learning from the experience of private industry, contracting the use of commercially-owned hybrid airships (at least initially), and gradually expanding HA missions as they are proven operationally, the DoD can begin to use this new technology to augment its current transportation network.

TRANSCOM should initially consider using HA initially in non-combat operations (HA/DR). This will allow crewmembers to gain experience, and expose the craft to rigorous operational environments. This will allow for tactics, techniques and procedures (TTP) to be developed and verified, while also providing the opportunity for modification—or even redesign—of parts of the new hybrid airships.

A 50-ton HA is a likely candidate to shoulder a share of the US TRANSCOM lift mission within the next 10 years (RAND, 2008:3). This was demonstrated in this paper. A fleet of six hybrid aircraft capable of lifting 50 tons can provide augmenting lift capability, while potentially keeping operating costs low. (The number six was chosen so that a notional maintenance reliability rate of 0.90 would ensure production of five HA sorties)

Recommendations for Future Research

The LP model used in this analysis was fairly sensitive. Its simple construction can give the user clarity into the times and cargo loads that can be moved in an intratheater scenario. Initial response (speed/time) is the most critical factor considered (while moving the minimum payload). However, the model does not distinguish between 200 tons of cargo arriving only 0.1 hours prior to a ship carrying thousands of tons of cargo, for example. Therefore, further modeling and simulation might smooth out the abrupt differences used to rank order some of the lift combinations advocated by this paper.

Another area ripe for research is analysis of intratheater fleet mix using cargo demands greater than 200 tons. For example, two more rounds of analysis, using 500 ton and 1,000 ton daily requirements might help confirm or refute the patterns shown in this paper's analysis. This research might also help more definitively establish whether TRANSCOM can make use of hybrid airships that carry payloads heavier than 50 tons.

A third recommendation for future HA research is generating more robust timelines at both the strategic and operational levels. At the strategic level, funding and technology will dictate when (and if) HA are a realistic option for TRANSCOM. If they are, then perhaps 40 to 50 ton HA are good test cases to determine if larger sized (or scale) HA implementation should be pursued. At the operational level, the proper phasing of HA in an operation is important—particularly when complementing sealift. Appendix G touched briefly on this concept. However, many sealift factors such as activation/deactivation, loading, port times, war risk insurance, canal fees, and percentage of cargo space used have significant effects on cost and delivery time. The insatiable demand for AMC crews and assets also determines their availability and reliability in HA/DR operations (and therefore the possible contribution of hybrid airships). More detailed work can be accomplished in this area, to flesh out the niche capabilities of HA for short, medium, or long duration operations.

An article published on 28 March 2011 stated that Canada's Aviation Capital Enterprises has agreed to purchase some 20-ton payload hybrid airships from Lockheed Martin. The initial delivery date is in 2012. These "Sky Tug" variants will use technology developed for the P-791 to provide logistics support for Canadian oil fields. This should allow the engine thrust to be vectored to provide a true vertical takeoff and landing (VTOL) capability, and permit landing on unimproved ground or even water (Page, 2011:1). TRANSCOM can monitor the fielding and operation of the "Sky Tug." This may spur more research into smaller payload HA than were examined in this paper. This may support using several 20-ton HA in concert with (or in place of) smaller payload conventional aircraft like the C-130, C-27J, or CH-47. Or, this analysis may be used to validate this paper's finding that HA payloads of 40 to 50 tons have utility in intratheater operations.

Synchronization of sea and air lift (including HA) will be especially important in scenarios like Operation Unified Response, for several reasons. First, the seaport was not able to receive large shipments until nearly two weeks after the earthquake. Second, the airfield could not accommodate high maximum on ground (MOG) levels. Finally, the relief distribution sites were not collocated with the sea or air port (VanHoof, 2011).

If no sealift is possible, or no nearby airfields can support conventional fixed or rotary wing aircraft, then HA might prove critical to successful future operations. Primitive clear areas may be the only way for lift assets like HA to access some regions. Therefore, distance and clear area required for takeoff and landing can be vital pieces of information. This is directly tied to the future capability of HA. For example, Appendix K shows the locations of several aid distribution points (DP) used in Operation Unified Response. DPs 4, 5A, and 6 have been assessed as potential HA landing sites. However, the amount of clear area there is relatively low. DP 4 measures roughly 200 meters by 220 meters. DP 5A has a circular clear area estimated at only 450 feet in diameter. DP 6 is also circular, and measures about 1,000 feet in diameter (VanHoof, 2011). LZ dimensions like these require vertical (or near-vertical) takeoff and landing capability.

If HA cannot obtain easy access to ballast material, or realistically employ systems like COSH to compress and store helium, one of their chief operational advantages might be lost. This should be a top priority for research. The US Defense Intelligence Agency (DIA) can assist in this effort by analyzing potential off-airport landing zones (LZ) that might be compatible with HA operations.

Researchers should also continue to develop innovative concepts of operation for dealing with considerations like ballast management. Past ideas have included making quick intermediate stops to onload water as close to the landing zone as possible (Rapp, 2006:63). One notion entertained during the production of this paper was intentionally starting a relatively short intratheater mission with excess ballast on board. This would allow the HA static heaviness to remain above zero, even if weight was reduced more than anticipated due to higher fuel burn rates. Most of this ballast material could be offloaded just prior to landing.

Although this would sacrifice some payload capacity and range performance, it would theoretically allow the percent heaviness to be reduced to just above zero before landing. This should allow the HA to descend at a very slow vertical velocity, thus reducing (or eliminating) the need for forward travel distance for deceleration and landing. (But, this assumes it will not be blown off the intended landing point/zone by wind, or possibly need an assist from thrust vectoring of the engines).

Of course, as cargo is offloaded, some method of compensating for the reduced weight (and therefore increased buoyancy) would have to be employed. This could be accomplished by onloading ballast material, engine thrust vectoring, or other proprietary systems that “suck” the airship to the ground (Rapp, 2006:31). If ballast material is required, but not readily available, one solution might be the use of an advance “ballast ship” that is used to preposition ballast material at the intended landing zone.

No matter what technology is employed, some sources are skeptical about the procurement costs of HA. A 2004 Congressional Research Service (CRS) report to Congress notes that it will be challenging to develop and procure HA during periods of reduced DoD

budget (Bolkcom, 2004:CRS-6). Therefore, a comparison of various HA ownership or leasing arrangements may be useful to TRANSCOM.

Factors to consider are whether hybrid airships will be contractor-owned or DoD owned. Other questions include designating the operating agency (private, military, or a combination of both). If HA are commercially operated, DoD should investigate whether an arrangement similar to the civil reserve air fleet (CRAF) will be beneficial, or if it should retain explicit use rights to a certain number of HA.

Other cost comparison factors include fuel and helium costs. The US Defense Logistics Agency (DLA) might offer insight into the energy sources (helium and petroleum) needed to lift and propel hybrid airships. Planned HA engine configurations should be carefully considered.

Proposed HA engine designs should be scrutinized for efficiency, but still provide enough power to attain minimum specified speed, range, and altitude. Any designs that necessitate extended use of HA engines while on the ground (for example, thrust vectoring for mooring) must also be examined. These variables will directly affect fuel costs.

The current and predicted price of helium should also be considered. The disposition of the US strategic helium reserve will also factor into this analysis (RAND, 2008:34). Additionally, the proposed concepts for helium usage must be examined. If systems like COSH are employed, helium replenishment intervals will likely be increased, but will still exist. For any HA that do not use such technology, and simply vent helium to reduce buoyancy, in-theater supply and servicing facilities must be established.

Appendix A: Examples of HA Concepts/Prototypes

Figure 1. Aeroscraft ML 866 Concept
Source: Aeroscraft Website

Figure 2. Skyhook HLV Concept
Source: Boeing Website

Figure 3. HAV Skykitten
Source: Aerospace Technology Website

Figure 4. HAV Sky Cat 20 Concept
Source: Aerospace Technology Website

Figure 5. HAV Condor 104
Source: USTRANSCOM

Figure 6. Lockheed Martin P-791
Source: Lockheed Martin Website

Appendix B: Conventional Airlift Planning Data

Aircraft Type	Pallet Positions	Cargo (s/t)		Passengers[4,6]		Standard NEO Passengers
		ACL[2]	Planning[3]	ACL	Planning	
C-9	-	-	-	40	32	40
C-130	6	17	12	90	80	92/74[5]
C-141	13	30	19	153	120	200/153[5]
C-17	18	65	45	101	90	101
C-5	36	89	61.3	73	51	73

Type	Mach	500 nm	1000 nm	1500 nm	2000 nm	2500 nm	3000 nm	3500 nm	4000 nm	4500 nm	5000 nm	5500 nm	6000 nm
C-9	0.78	344	397	414	420	421	-	-	-	-	-	-	-
C-130	0.49	242	266	272	273	272	271	-	-	-	-	-	-
C-141	0.74	332	380	396	401	401	401	404	407	409	410	-	-
C-17	0.76	335	384	400	405	406	406	409	412	-	-	-	-
C-5	0.77	341	393	410	415	416	416	420	422	424	426	428	429

Figure 7. Conventional Airlift Payload and Block Speed Information

Source: AFPAM 10-1403, 18 December 2003:12-13

Appendix C: Air Mobility Command Airlift Reimbursement Rates

Table 8. AMC Hourly Operating Costs

FY2011				
MDS	**DoD**	**Oth Fed**	**FMS**	**Public**
C-130E	$7,614	$7,937	$7,953	$8,254
C-130H	$6,964	$7,330	$7,348	$7,623
C-130J	$5,080	$5,281	$5,291	$5,492
C-17A	$11,658	$11,859	$11,869	$12,333
C-5A	$30,966	$31,252	$31,268	$32,502
C-5B	$26,485	$26,771	$26,787	$27,842
C-5C	$27,337	$27,665	$27,684	$28,772
C-5M	$40,702	$40,988	$41,004	$42,628

Source: Data extracted from AFI 65-503, Table 15-1

Appendix D: Sealift Vessel Payload Calculations

Table 9. Sealift Vessel Payload Capacity Expressed in Short Tons

	Payload Capacity		
Vessel	**Square Feet**	**TEU**	**Short Tons**
4,000 Container Ship		4,000	32,000
1,000 Container Ship		1,000	8,000
LMSR	196,000 to 255,000*		9,800 to 12,750 (mean = 11,275)
FSS	199,000 to 207,000	225	1,800**
RRF RORO	94,000 to 140,000*		4,700 to 7,000 (mean = 5,850)
Break Bulk	Not used by DoD	-	-
JHSV	20,000		600***
Army LSV		("24 C-17s")	1,800
Army LCU		("4 C-17s")	300

*LMSR capacity = 380,000 square feet. However, 196,000-225,000 square feet figures account for 65% "stowage factor." RRF RORO numbers shown also account for 65% stowage factor.
**225 TEU at 8 tons per TEU = 1,800 tons. (Average square footage conversion, using median value of 203,000 square feet yields 10,150 tons). More conservative value of 1,800 tons used.
***JHSV normally reaches space limit before reaching 1,000 ST (20,000 square feet / 20). 600 ST is best estimate.

Source: Author. Conversion data from USTRANSCOM (16 December 2010). US MSC and RRF vessel specifications from USTRANSCOM (16 December 2010), MSC (Clark, 2011), and US Navy official website. US Army vessel specifications from US SDDC presentation (December 2010).

Appendix E: LMSR Operating Costs

Table 10. LMSR Daily Operating Cost Calculations

Ship Class	**Shugart / Yano**	**Gordon / Gilliland**	**Watson**	**Bob Hope**	
Speed (knots)					**Average (Mean)**
19	$67,000	$77,000	$93,000	$83,000	$80,000
24	$72,000	$96,000	$120,000	$102,000	$97,500

Source: Author. Data from MSC and the MSC "Voyage Calculator" Excel workbook.
Canal fees, war risk insurance, and activation/deactivation cost not applicable/not included.
Calculations do include 5 total days in port (3 days in CONUS, and 2 days in Port au Prince).

Appendix F: JHSV Range Calculations

(1) Range with 0 payload: 4700 NM

Range with 600 tons payload: 1200 NM

4700 NM – 1200 NM = 3500 NM

$\frac{3500\ NM}{6}$ = 583.3 NM increase per 100 tons payload

(Round down to 583 NM)

(2) Range with 200 tons payload:

1200 NM + (583 NM x 2) = 1200 NM + 1166 NM = <u>2366 NM</u>

Appendix G: Notional Movement Timeline

Day:	0	1	2	3	4	5	6	7	8	9	10
	Sealift Readied / Loaded			Underway	Sealift Arrives	Sealift Continues					
	Airlift Prep	Dep/Arr	Dep/Arr		Dep/Arr		Dep/Arr		Dep/Arr		
	HA Prep	Dep/Arr	Dep/Arr	Dep/Arr	Dep/Arr	Dep/Arr		Dep/Arr		Dep/Arr	Dep/Arr

Figure 8. HA as "Gap Filler" During Initial Sealift
Source: Author.

48 Hours assumed for making sealift vessels ready/loading (From ASCAM 3.2). Based on LP model, CONUS to Haiti sealift movement leg could take 27 to 96 hours, depending on which vessel is used.

Appendix H: LP Model Interface Screen Shot Examples

Aircraft / Ship	Planning Payload Capacity (tons)	Block Speed (NM/hour) (<= 2500 NM)	Number Available	MX Reliability	Number Useable	Air / Sea Distance (NM)	Time per Mission (hrs)	Missions Assigned / Required	Cargo Moved (Stons)	Operating Cost per Hour	Cost CHS-Haiti
C-5	61.3	416	9	0.75	6	956	2.3	4.0	245.2	$26,485	$243,458
C-17	45	406	9	0.90	8	956	2.4	0.0	0	$11,658	$0
C-130	12	272	29	0.90	26	956	3.5	0.0	0	$5,080	$0
								0.0			
HA-1	30	80	0	0.90	0	956	12.0	0.0	0		
HA-2	50	80	9	0.90	8	956	12.0	0.0	0		
HA-3 (31-49 ton)	43	80	0	0.90	0	956	12.0	0.0	0		
								0.0			
4000 Container	32,000	22	9	1.00	9	956	43.5	0.0	0	$3,500	$0
1000 Container	8,000	22	9	1.00	9	956	43.5	0.0	0	$2,300	$0
LMSR	11,275	24	9	1.00	9	956	39.8	0.0	0	$4,000	$0
FSS	1,800	33	9	1.00	9	956	29.0	0.0	0	$6,400	$0
RRF RORO	5,850	17	9	1.00	9	956	56.2	0.0	0	$2,700	$0
JHSV	600	35	9	1.00	9	956	27.3	0.0	0	$6,100	$0
Army LSV	1,800	11	9	1.00	9	956	86.9	0.0	0	$888	$0
Army LCU	300	10	9	1.00	9	956	95.6	0.0	0	$459	$0

Total Cargo Requirement (Stons): 200.0

Total Cargo Moved (Stons): 245.2
Total Time Required (Hours): 9.2
Operating Cost (to Haiti): $243,458

USER INPUT CELLS ARE DESIGNATED IN BLUE. FOR EXAMPLE:

Figure 9. Microsoft Excel Workbook Interface for LP Model ("Step One")
Source: Author

Aircraft / Ship	Planning Payload Capacity (tons)	Block Speed (NM/hour) (<= 2500 NM)	Number Available	MX Reliability	Number Useable	Air / Sea Distance (NM)	Time per Mission (hrs)	Missions Assigned / Required	Cargo Moved (Stons)	Operating Cost per Hour	Cost CHS-Haiti
C-5	61.3	416	0	0.75	0	956	2.3	0.0	0	$26,485	$0
C-17	45	406	0	0.90	0	956	2.4	0.0	0	$11,658	$0
C-130	12	272	29	0.90	26	956	3.5	0.0	0	$5,080	$0
								0.0			
HA-1	30	80	0	0.90	0	956	12.0	0.0	0		
HA-2	50	80	9	0.90	8	956	12.0	0.0	0		
HA-3 (31-49 ton)	43	80	0	0.90	0	956	12.0	0.0	0		
								0.0			
4000 Container	32,000	22	9	1.00	9	956	43.5	0.0	0	$3,500	$0
1000 Container	8,000	22	9	1.00	9	956	43.5	0.0	0	$2,300	$0
LMSR	11,275	24	9	1.00	9	956	39.8	0.0	0	$4,000	$0
FSS	1,800	33	9	1.00	9	956	29.0	0.0	0	$6,400	$0
RRF RORO	5,850	17	9	1.00	9	956	56.2	0.0	0	$2,700	$0
JHSV	600	35	9	1.00	9	956	27.3	1.0	600	$6,100	$166,617
Army LSV	1,800	11	9	1.00	9	956	86.9	0.0	0	$888	$0
Army LCU	300	10	9	1.00	9	956	95.6	0.0	0	$459	$0

Total Cargo Requirement (Stons): 200.0

Total Cargo Moved (Stons): 600
Total Time Required (Hours): 27.3
Operating Cost (to Haiti): $166,617

USER INPUT CELLS ARE DESIGNATED IN BLUE. FOR EXAMPLE:

Figure 10. Microsoft Excel Workbook Interface for LP Model ("Step Two")
Source: Author

Aircraft / Ship	Planning Payload Capacity (tons)	Block Speed (NM/hour)	Number Available	MX Reliability	Number Useable	Air / Sea Distance (NM)	Time per Mission (hrs)	Missions Assigned / Required	Cargo Moved (Stons)	Operating Cost per Hour	Cost CHS-Haiti
		(<= 2500 NM)									
C-5	61.3	416	0	0.75	0	956	2.3	0.0	0	$26,485	$0
C-17	45	406	0	0.90	0	956	2.4	0.0	0	$11,658	$0
C-130	12	272	29	0.90	26	956	3.5	0.0	0	$5,080	$0
								0.0			
HA-1	30	80	0	0.90	0	956	12.0	0.0	0		
HA-2	50	80	9	0.90	8	956	12.0	4.0	200		
HA-3 (31-49 ton)	43	80	0	0.90	0	956	12.0	0.0	0		
								0.0			
4000 Container	32,000	22	0	1.00	0	956	43.5	0.0	0	$3,500	$0
1000 Container	8,000	22	0	1.00	0	956	43.5	0.0	0	$2,300	$0
LMSR	11,275	24	0	1.00	0	956	39.8	0.0	0	$4,000	$0
FSS	1,800	33	0	1.00	0	956	29.0	0.0	0	$6,400	$0
RRF RORO	5,850	17	0	1.00	0	956	56.2	0.0	0	$2,700	$0
JHSV	600	35	0	1.00	0	956	27.3	0.0	0	$6,100	$0
Army LSV	1,800	11	0	1.00	0	956	86.9	0.0	0	$888	$0
Army LCU	300	10	0	1.00	0	956	95.6	0.0	0	$459	$0
Total Cargo Requirement (Stons):		200.0				Total Cargo Moved (Stons):			200		
						Total Time Required (Hours):			47.8		
						Operating Cost (to Haiti):			$0		
USER INPUT CELLS ARE DESIGNATED IN BLUE. FOR EXAMPLE:											

Figure 11. Microsoft Excel Workbook Interface for LP Model ("Step Three")
Source: Author

Aircraft / Ship	Planning Payload Capacity (tons)	Block Speed (NM/hour)	Number Available	MX Reliability	Number Useable	Air / Sea Distance (NM)	Time per Mission (hrs)	Missions Assigned / Required	Cargo Moved (Stons)	Operating Cost per Hour	Cost CHS-Haiti
		(<= 2500 NM)									
C-5	61.3	416	0	0.75	0	956	2.3	0.0	0	$26,485	$0
C-17	45	406	0	0.90	0	956	2.4	0.0	0	$11,658	$0
C-130	12	272	29	0.90	26	956	3.5	3.0	36	$5,080	$53,564
								0.0			
HA-1	30	80	0	0.90	0	956	12.0	0.0	0		
HA-2	50	80	0	0.90	0	956	12.0	0.0	0		
HA-3 (31-49 ton)	43	80	5	0.90	4	956	12.0	4.0	172		
								0.0			
4000 Container	32,000	22	0	1.00	0	956	43.5	0.0	0	$3,500	$0
1000 Container	8,000	22	0	1.00	0	956	43.5	0.0	0	$2,300	$0
LMSR	11,275	24	0	1.00	0	956	39.8	0.0	0	$4,000	$0
FSS	1,800	33	0	1.00	0	956	29.0	0.0	0	$6,400	$0
RRF RORO	5,850	17	0	1.00	0	956	56.2	0.0	0	$2,700	$0
JHSV	600	35	0	1.00	0	956	27.3	0.0	0	$6,100	$0
Army LSV	1,800	11	0	1.00	0	956	86.9	0.0	0	$888	$0
Army LCU	300	10	0	1.00	0	956	95.6	0.0	0	$459	$0
Total Cargo Requirement (Stons):		200.0				Total Cargo Moved (Stons):			208		
						Total Time Required (Hours):			58.3		
						Operating Cost (to Haiti):			$53,564		
USER INPUT CELLS ARE DESIGNATED IN BLUE. FOR EXAMPLE:											

Figure 12. Microsoft Excel Workbook Interface for LP Model ("Step Five")
Source: Author

Appendix I: Results From Model Runs

Table 11. "Step One" Results From Model Runs for Airlift, Sealift, and HA Available

Solution "Rank Order" (Least Total Enroute Time)	Aircraft / Ships Used	Total Enroute Time (hrs) (Charleston to Port au Prince)	Total Cargo (ST) (rounded to nearest ST)	Cost (Charleston to Port au Prince)
1	4 x C-5	9.2	245	$243,458
2	5 x C-17 (no C-5 available)	11.8	225	$137,254

Source: Author

Table 12. "Step Two" Results From Model Runs. (No C-5 or C-17 Available)

Solution "Rank Order" (Least Total Enroute Time)	Aircraft / Ships Used	Total Enroute Time (hrs) (Charleston to Port au Prince)	Total Cargo (ST) (rounded to nearest ST)	Cost (Charleston to Port au Prince)
1	1 x JHSV	27.3	600	$166,617 (prorated) $292,000 (2 days)
2	1 x FSS	29	1,800	$185,406 (prorated) $308,000 (2 days)
3	1 x LMSR	39.8	11,275	$159,333 (prorated) $195,000 (2 days)
4	1 x 4,000 Container	43.5	32,000	$152,091 (prorated) $168,000 (2 days)
5	1 x 1,000 Container	43.5	8,000	$99,945 (prorated) $112,000 (2 days)
6	4 x 50-ton HA	47.8	200	(HA Cost TBD)

Source: Author

Table 13. "Step Three" Results From Model Runs for Airlift and HA Only (No Sealift)

C-5	C-17	C-130	50-ton HA	30-ton HA	Total Flight Time (hrs)	Total Cargo (ST) (rounded to nearest ST)	Cost (Charleston to Port au Prince)
Step 3a. (C-5 as main independent variable. Measures use of C-5, C-17, C-130, and 50-ton HA.)							
4	0	0	0	N/A	9.2	245	$243,458
3	1	0	0	N/A	9.3	229	$210,045
3	N/A	2	0	N/A	13.9	208	$218,303
3	N/A	N/A	1	N/A	18.8	234	$182,594 (+ HA cost)
2	2	0	0	N/A	9.3	213	$176,631
2	N/A	3	1	N/A	27.1	209	$175,293 (+ HA cost)
2	N/A	N/A	2	N/A	28.5	223	$121,729 (+ HA cost)
1	4	0	0	N/A	11.7	241	$170,668
1	N/A	0	3	N/A	38.1	211.3	$60,865 (+ HA cost)
Step 3b. (C-17 as main independent variable. Measures use of C-17, C-130, and 50-ton HA.)							
N/A	5	0	0	N/A	11.8	225	$137,254
N/A	4	2	0	N/A	16.4	204	$145,513
N/A	3	2	1	N/A	26.0	209	$118,062 (+ HA cost)
N/A	2	1	2	N/A	32.1	202	$72,756 (+ HA cost)
N/A	1	1	3	N/A	41.7	207	$45,306 (+ HA cost)
Step 3c. (50-ton HA as main independent variable. Measures relationship with C-130.)							
N/A	N/A	0	4	N/A	47.8	200	(HA cost)
N/A	N/A	5	3	N/A	53.4	210	$89,274 (+ HA cost)
N/A	N/A	9	2	N/A	55.5	208	$160,692 (+ HA cost)
N/A	N/A	13	1	N/A	57.6	206	$232,111 (+ HA cost)
N/A	N/A	17	0	N/A	59.8	204	$303,530

Note: "N/A" indicates aircraft type set to none available. A "0" indicates that type aircraft was/were available, but none were chosen in that particular model solution.

Source: Author

Table 14. "Step Four" Results From Manual Incremental Analysis of Model Runs for C-130 and 30-ton HA Only

C-5	C-17	C-130 (12 ST Payload)	30-ton HA	Total Flight Time (hrs)	Total Cargo (ST) (rounded to nearest ST)	Cost (Charleston to Port au Prince)
N/A	N/A	17	0	59.8	204	$303,530
N/A	N/A	16				
N/A	N/A	15	1	64.7	210	$267,821 (+ HA cost)
N/A	N/A	14				
N/A	N/A	13				
N/A	N/A	12	2	66.1	204	$214,256 (+ HA cost)
N/A	N/A	11				
N/A	N/A	10	3	71.0	210	$178,547 (+ HA cost)
N/A	N/A	9				
N/A	N/A	8				
N/A	N/A	7	4	72.4	204	$124,983 (+ HA cost)
N/A	N/A	6				
N/A	N/A	5	5	77.3	210	$89,274 (+ HA cost)
N/A	N/A	4				
N/A	N/A	3				
N/A	N/A	2	6	78.7	204	$35,709 (+ HA cost)
N/A	N/A	1				
N/A	N/A	0	7	83.7	210	(HA cost)

Source: Author

Table 15. "Step Five" Results From Manual Sensitivity Analysis of Model Runs for C-130 and HA Only (31 to 49 ton HA payloads

C-5	C-17	C-130 (12 ST Payload)	Number of HA	HA Payload Weight (ST)	Total Flight Time (hrs)	Total Cargo (ST) (rounded to nearest ST)	Cost (Charleston to Port au Prince)
N/A	N/A	1	4	49	51.3	208	$17,855 (+ HA cost)
N/A	N/A	1	4	48	51.3	204	$17,855 (+ HA cost)
N/A	N/A	1	4	47	51.3	200	$17,855 (+ HA cost)
N/A	N/A	2	4	46	54.8	208	$35,709 (+ HA cost)
N/A	N/A	2	4	45	54.8	204	$35,709 (+ HA cost)
N/A	N/A	2	4	44	54.8	200	$35,709 (+ HA cost)
N/A	N/A	3	4	43	58.3	208	$53,564 (+ HA cost)
N/A	N/A	0	5	42	59.8	210	(HA cost)
N/A	N/A	3	4	41	58.3	200	$53,564 (+ HA cost)
N/A	N/A	17	0	40	59.8	204	$303,530
N/A	N/A	17	0	39	59.8	204	$303,530
N/A	N/A	17	0	38	59.8	204	$303,530
N/A	N/A	17	0	37	59.8	204	$303,530
N/A	N/A	17	0	36	59.8	204	$303,530
N/A	N/A	17	0	35	59.8	204	$303,530
N/A	N/A	17	0	34	59.8	204	$303,530
N/A	N/A	17	0	33	59.8	204	$303,530
N/A	N/A	17	0	32	59.8	204	$303,530
N/A	N/A	17	0	31	59.8	204	$303,530

Source: Author

Appendix J: Cost Comparison Data (Conventional Airlift and HA)

Table 16. Maximum Operating "Break Even" Cost for 50-ton HA

C-5	C-17	C-130	50-ton HA	Cost (Charleston to Port au Prince)	Airlift Cost Difference	Maximum HA "Break Even" Hourly Cost
Case 1 (from "Step 3a"): $243,458 maximum airlift cost						
4	0	0	0	$243,458	$0	
3	1	0	0	$210,045	$33,413	
3	N/A	2	0	$218,303	$25,155	
3	N/A	N/A	1	$182,594 (+ HA cost)	$60,864	$5,072
2	2	0	0	$176,631	$66,827	
2	N/A	3	1	$175,293 (+ HA cost)	$68,165	$5,680
2	N/A	N/A	2	$121,729 (+ HA cost)	$121,729	$5,072
1	4	0	0	$170,668	$72,790	
1	N/A	0	3	$60,865 (+ HA cost)	$182,593	$5,072
Case 2 (from "Step 3b": $145,513 maximum airlift cost						
N/A	5	0	0	$137,254	$8,259	
N/A	4	2	0	$145,513	$0	
N/A	3	2	1	$118,062 (+ HA cost)	$27,451	$2,288
N/A	2	1	2	$72,756 (+ HA cost)	$72,757	$3,032
N/A	1	1	3	$45,306 (+ HA cost)	$100,207	$2,784
Case 3 (from "Step 3c"): $303,530 maximum airlift cost						
N/A	N/A	0	4	(HA cost)	$303,530	$6,324
N/A	N/A	5	3	$89,274 (+ HA cost)	$214,256	$5,952
N/A	N/A	9	2	$160,692 (+ HA cost)	$142,838	$5,952
N/A	N/A	13	1	$232,111 (+ HA cost)	$71,419	$5,952
N/A	N/A	17	0	$303,530	$0	

Source: Author

Table 17. Maximum Operating "Break Even" Cost for 30-ton HA (versus C-130)

C-5	C-17	C-130 (12 ST Payload)	30-ton HA	Cost (Charleston to Port au Prince)	Airlift Cost Difference	Maximum HA "Break Even" Hourly Cost
Case 4 (from "Step 4"): $303,530 maximum airlift cost						
N/A	N/A	17	0	$303,530	$0	
N/A	N/A	15	1	$267,821 (+ HA cost)	$35,709	$2,976
N/A	N/A	12	2	$214,256 (+ HA cost)	$89,274	$3,720
N/A	N/A	10	3	$178,547 (+ HA cost)	$124,983	$3,472
N/A	N/A	7	4	$124,983 (+ HA cost)	$178,547	$3,720
N/A	N/A	5	5	$89,274 (+ HA cost)	$214,256	$3,571
N/A	N/A	2	6	$35,709 (+ HA cost)	$267,821	$3,720
N/A	N/A	0	7	(HA cost)	$303,530	$3,613

Source: Author

Table 18. Maximum Operating "Break Even" Cost for Variable Payload HA (versus C-130)

C-5	C-17	C-130 (12 ST Payload)	Number of HA	HA Payload Weight (ST)	Cost (Charleston to Port au Prince)	Airlift Cost Difference	Maximum HA "Break Even" Hourly Cost
Case 5 (from "Step 5"): $303,530 maximum airlift cost							
N/A	N/A	1	4	49	$17,855 (+ HA cost)	$285,675	$5,952
N/A	N/A	1	4	48	$17,855 (+ HA cost)	$285,675	$5,952
N/A	N/A	1	4	47	$17,855 (+ HA cost)	$285,675	$5,952
N/A	N/A	2	4	46	$35,709 (+ HA cost)	$267,821	$5,580
N/A	N/A	2	4	45	$35,709 (+ HA cost)	$267,821	$5,580
N/A	N/A	2	4	44	$35,709 (+ HA cost)	$267,821	$5,580
N/A	N/A	3	4	43	$53,564 (+ HA cost)	$249,966	$5,208
N/A	N/A	0	5	42	(HA cost)	$303,530	$5,059
N/A	N/A	3	4	41	$53,564 (+ HA cost)	$249,966	$5,208
N/A	N/A	17	0	40	$303,530	$0	
N/A	N/A	17	0	39	$303,530	$0	
N/A	N/A	17	0	38	$303,530	$0	
N/A	N/A	17	0	37	$303,530	$0	
N/A	N/A	17	0	36	$303,530	$0	
N/A	N/A	17	0	35	$303,530	$0	
N/A	N/A	17	0	34	$303,530	$0	
N/A	N/A	17	0	33	$303,530	$0	
N/A	N/A	17	0	32	$303,530	$0	
N/A	N/A	17	0	31	$303,530	$0	

Source: Author

Appendix K: Operation Unified Response Distribution Sites

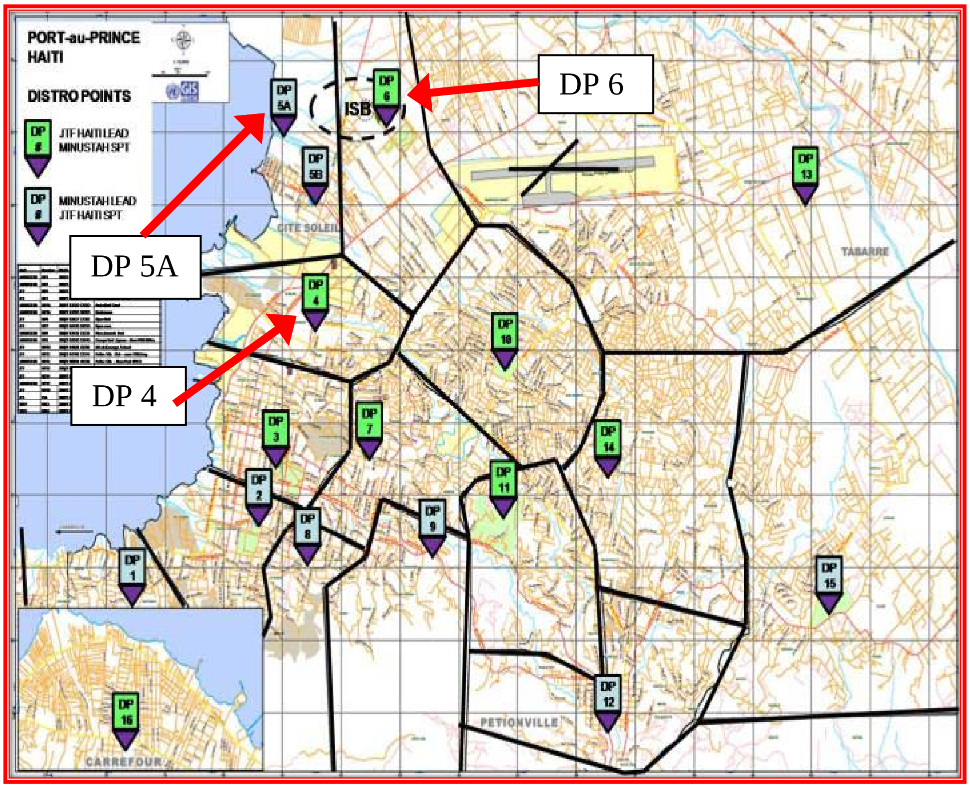


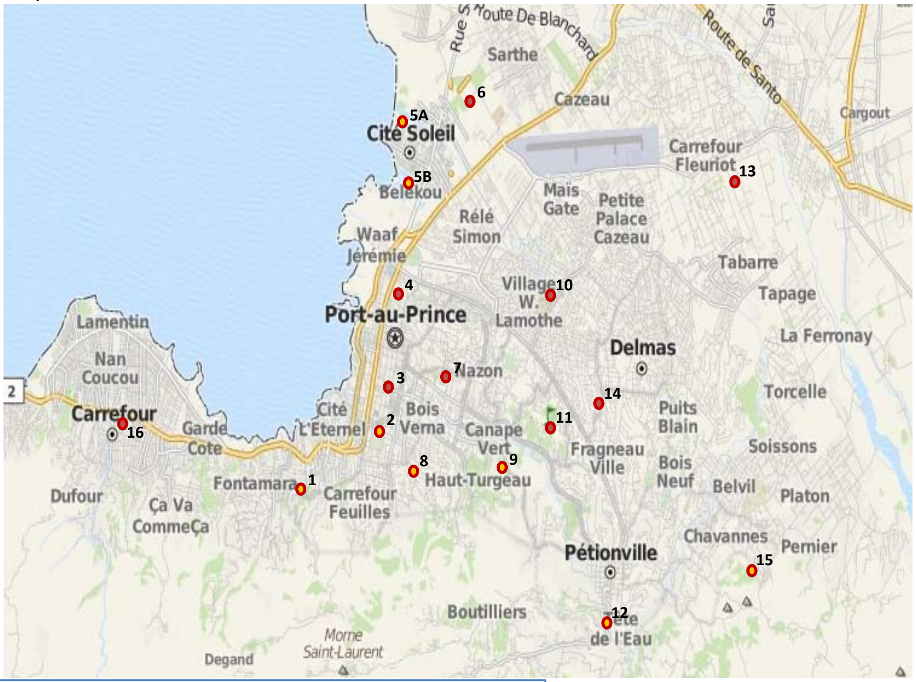
Figure 13. Distribution Points (DP)
Source: USTRANSCOM (Author highlighted DPs 4, 5A, and 6)

Hybrid Airship CONOP – Haiti Resupply

Travel Distances (km)

Ground routes (x1.4km*)

	Air	Ground
DP1	7	9.8
DP2	5	7
DP3	4	5.6
DP4	1.6	3.6
DP5A	1.8	2.5
DP5B	.8	1.1
DP6	2.7	3.8
DP7	4	5.6
DP8	5.5	7.7
DP9	6	8.4
DP10	4.7	6.6
DP11	6.2	8.7
DP12	10.3	14.4
DP13	9	12.6
DP14	7	9.8
DP15	11.3	15.8
DP16	10	14



*1.4km conversion factor is slightly longer than actual road distance, but has been accepted to account for detours due to collapsed infrastructure.

Figure 14. Potential HA Resupply Points in Haiti

Source: USTRANSCOM

List of Acronyms

AAA: Anti-aircraft artillery

AFPAM: Air Force Pamphlet

AMC: Air Mobility Command

AMPCALC: AMC Mobility Planner's Calculator

APOD: Aerial port of debarkation

APOE: Aerial port of embarkation

ASCAM: Airlift and sealift cycle analysis model

ATG: Advanced Technologies Group

BB: Break bulk

CBO: Congressional Budget Office

CONEMP: Concept of employment

CONUS: Continental United States

COSH: Control of static heaviness

CRAF: Civil Reserve Air Fleet

CRE: contingency response element

CRS: Congressional Research Service

DARPA: Defense Advanced Research Projects Agency

DIA: Defense Intelligence Agency

DLA: Defense Logistics Agency

DoD: Department of Defense

DP: Distribution point(s)

FSS: Fast sealift ship

HA: hybrid airship

HA/DR: humanitarian assistance / disaster relief

HAC: Hybrid Aircraft Corporation

HAF: Headquarters Air Force

HAV: Hybrid Air Vehicles

HLV: Heavy lift vehicle

JFTL: Joint future theater lift

JHSV: Joint high-speed vessel

LCU: Landing craft utility

LMSR: Large medium-speed roll-on / roll-off

LP: Linear programming

LSV: Logistics support vessel

LZ: Landing zone MSC: Military Sealift Command

MANPADS: man-portable air defense system

MC: Mission capable

MSL: Mean sea level

NM: Nautical mile(s)

POD: Port(s) of debarkation

POE: Port(s) of embarkation

RORO: Roll-on / roll-off

RRF: Ready reserve force

SAM: Surface to air missile

SDDC: Surface Deployment and Distribution Command

ST: Short tons

STOL: Short takeoff and landing

TEU: Twenty-foot equivalent unit

USAF: United States Air Force

USAID: United States Agency for International Development

USN: United States Navy

USS: United States Ship

USTRANSCOM: United States Transportation Command

VTOL: Vertical takeoff and landing

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"Oh, the Humanity": Hybrid Airships for Disaster Relief Operations

On 12 January 2010, a 7.0 magnitude earthquake devastated the nation of Haiti. It leveled much of the capital city of Port au Prince and the surrounding areas. Over 220,000 people were killed, and approximately 300,000 were injured. More than one million lost their homes in the disaster. The seaport at Port au Prince was severely damaged, but was repaired to a semi-operable state by 21 January. The city's main airport (Toussaint Louverture International) control tower was damaged. However, the runway and most other surfaces remained useable for air operations.

Humanitarian assistance and disaster relief operations (HA/DR) to Haiti began almost immediately. Aid from various nations, non-governmental organizations, and private parties began moving toward the island nation. The US military joint port opening team and contingency response element (CRE) arrived in Haiti less than 42 hours after the earthquake. By 15 January, the airport was receiving flights with aid cargo onboard. By 17 January, the airport that normally handled less than 20 flights per day was receiving well over 100 aircraft each day. Sealift "in earnest" began arriving on 25 January. Operations did not taper off significantly until a month later.

The US military delivered approximately 400,000 pounds (200 tons) to the region each day. However, airlift was expensive (ranging from $5,000 to nearly $27,000 per hour). Sealift was slow, and not even possible to Port au Prince during the first two weeks of HA/DR. A third method of delivery could have saved time and money in this effort.

Hybrid airships (HA) are currently being developed to move payloads at speeds about three times faster than a ship, but only one-third as quick as a conventional airplane. HA improve on the airships and blimps that rose to prominence in the early 20th Century. They use a combination of helium gas and an airfoil body shape to provide lift. HA capable of moving 50 tons or less are currently in the final stages of prototype development. Several designs seem feasible within the next few years. Private logging and oil drilling companies have shown significant interest in acquiring these craft.

If these small HA were available during the 2010 Haiti relief operations, they could have effectively and efficiently augmented USTRANSCOM's current airlift and sealift capability. For distances of 956 nautical miles (NM) from the US to Haiti, as many as five HA could have reduced or minimized the total time needed to move 200 tons of cargo by approximately 12 hours each day.

Based on 2011 cost data, if expenses for hybrid airships are held below $3,000 per hour, they can be cheaper to employ than C-17 airlifters or some sealifters. If HA can be operated at less than $5,000 per hour, they can be more efficient that C-5 or C-130 aircraft. These figures can be extrapolated to intratheater operations spanning distances of up to 2,500 NM.

USTRANSCOM should continue to examine intratheater options for HA. TRANSCOM should initially consider using HA initially in non-combat operations (HA/DR). This will allow crewmembers to gain experience, and expose the craft to rigorous operational environments. This will allow for tactics, techniques and procedures (TTP) to be developed and verified, while also providing the opportunity for modification—or even redesign—of parts of the new hybrid airships.

TRANSCOM needs these assets. The command should consider initially using a fleet of six hybrid aircraft capable of lifting 50 tons. Eventually, the US military should examine purchasing HA outright. However, in the early phases of this venture, leasing or contracting from commercial operators can help hedge against technology obsolescence. This is a viable option if the initial missions will be into non-combat areas.

Using hybrid airships will allow vital supplies to reach the point of need before ships can get there, and at less cost than most airlift fleets. In today's "tug of war" between effectiveness and efficiency, HA can provide the niche capability to satisfy both. When used in concert with conventional airlift and sealift platforms, TRANSCOM will have a complete set of intratheater movement options for the United States military.

Major Lynch is a C-17 pilot and ASAM student.
Keywords: Hybrid Airships, Intratheater, Disaster Assistance, Humanitarian Relief, Haiti, Unified Response

Hybrid Airships: Intratheater Operations Cost-Benefit Analysis

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Issue:

USTRANSCOM tasked to "identify the use/need/capability gaps for hybrid airship employment"

Research Hypothesis:

Hybrid airships (HA) can be used to augment USTRANSCOM's current airlift and sealift fleet for intratheater cargo movement

:

Research Focus:

(1) Discuss the development, capabilities, and limitations of hybrid airships
(2) Identify where HA might be used to minimize or reduce the time required to move humanitarian assistance / disaster relief (HA/DR) cargo to the area of need
(3) Associate operating costs with various combinations of HA, conventional airlift, and sealift used to transport relief supplies across intratheater distances

Methodology:

-Excursion from base scenario of 2010 Haiti HA/DR
-Linear program used to minimize time to move 200 tons / day from CONUS to Haiti
-Operating cost data then injected to determine maximum HA operating costs (where HA might be financially less expensive to operate)
-Various airlift and sealift assets compared to 3 notional types of HA:
-50 ton payload
-30 ton payload
-31 to 49 ton payload

Results:

- To move 200 tons 2,500 nautical miles (NM) , up to 5 HA (each capable of lifting 40 to 50 tons) can help reduce/minimize total cargo movement time

-Operating Cost: May be efficient if between $3,000-$5,000 / hour

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14. ABSTRACT
This paper examines the potential use of hybrid airships (HA) in an intratheater humanitarian assistance scenario. A linear programming model was used to study various mixes of hybrid airships, conventional airlifters, and sealift vessels. The main goal was minimizing the time needed to move 200 tons of cargo each day. The secondary aim was determining whether HA might be employed at less expense than conventional airlift or sealift assets.

The analysis determined that HA can be used to effectively and efficiently augment USTRANSCOM's current airlift and sealift capability. For medium-range distances (approximately 2,500 nautical miles one way), as many as five HA (each capable of lifting 40 to 50 tons) can help reduce or minimize total cargo movement time.

Based on 2011 operating costs, if expenses for hybrid airships are held below $3,000 per hour, they can be cheaper to employ than C-17s. If small cargo totals (i.e. 200 tons) must be moved as quickly as possible (or during sealift transit), then HA operating costs of $3,000 per hour or less also make them a less costly option compared to sealift. In comparison to C-5 and C-130 aircraft, HA "break even" hourly operating costs might be as high as $5,000.

15. SUBJECT TERMS
Hybrid Airships, Intratheater, Disaster Assistance, Humanitarian Relief, Haiti, Unified Response, Cost

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